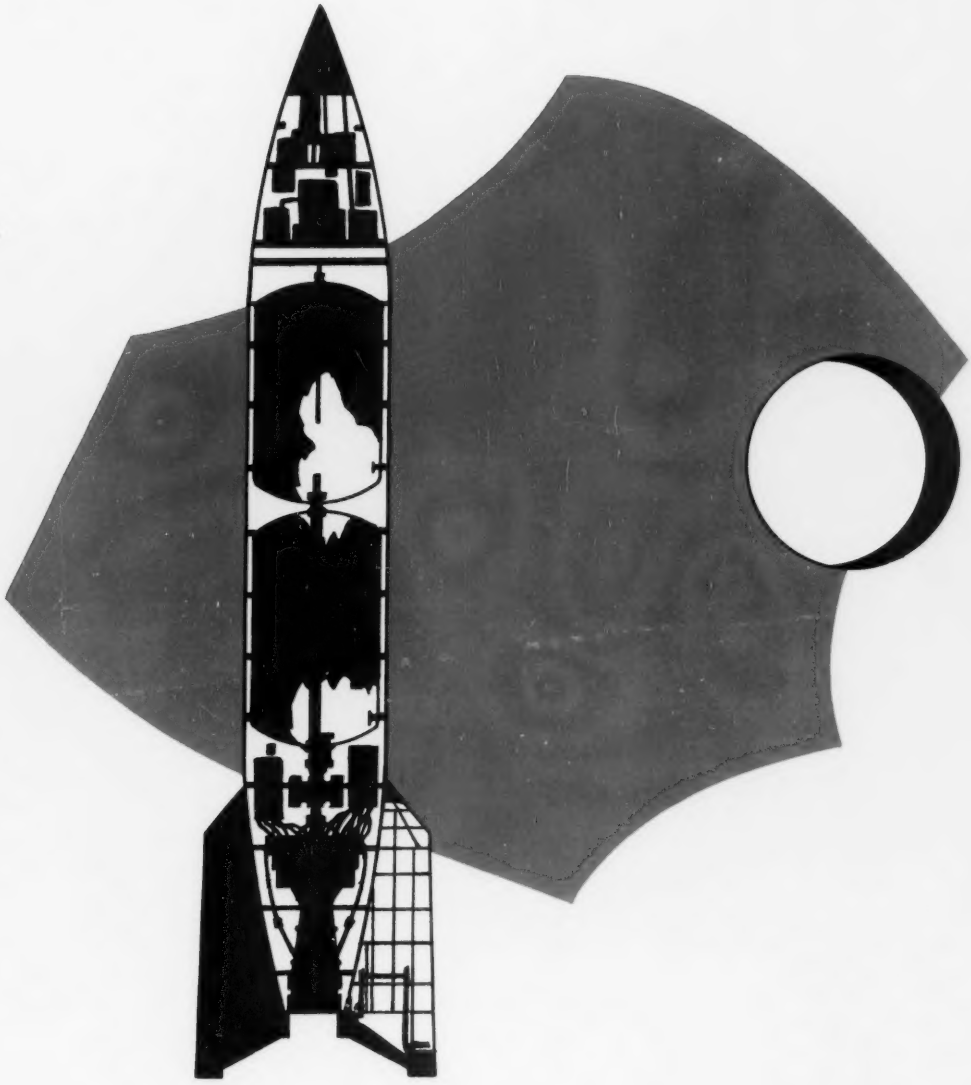
tech engineering news



november 1954

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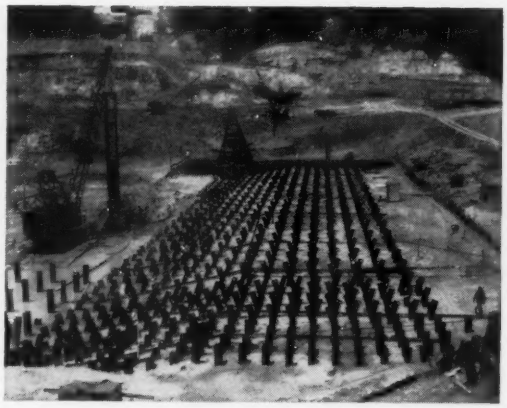
Famous Finger of Metal and stone pointing 1472 feet into the sky is The Empire State Building in New York City. This mightiest of buildings makes liberal use of Stainless Steel for both decorative and utilitarian purposes: in vertical strips beside the windows, in bands around the tower, in the two entrance corridors. "Maintenance?" said the assistant operating manager when asked about the exterior Stainless Steel. "What maintenance? We haven't touched the stainless steel since it was installed. And the condition of the steel is as good as ever." Not a bad record after more than 20 years.



Dragon's Teeth Sprouting? No, these are steel bearing piles in the foundation of a dam spillway. When the dam is finished, you'll never know the steel piles are there. But they'll be working just the same, for strength and safety, as enduring steel so often works unseen in buildings, highways, pipelines and power plants.

This Baby Sitter is Galvanized! In truth, a sturdy, good-looking Cyclone Fence is a dependable baby sitter. For it makes a safe home playground out of your yard. It keeps youngsters, absorbed in play, from stepping accidentally into the path of passing traffic. It prevents stray dogs from molesting your children or flowers. Cyclone Fence, made by U. S. Steel, is further evidence that only steel can do so many jobs so well.

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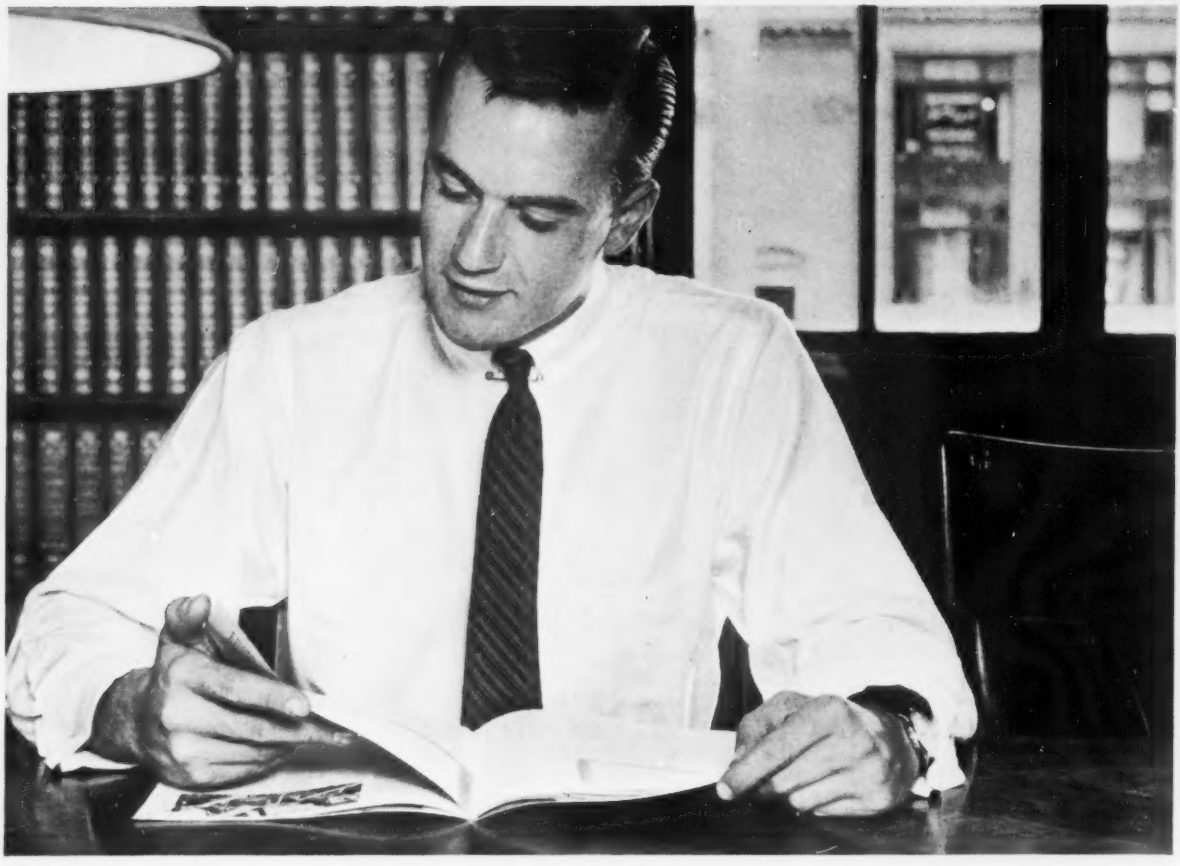

HE'S STUDYING A GM TEXTBOOK

YES, ever since our first issue—*June-July 1953*—the *General Motors Engineering Journal* has been welcomed by engineering faculties and students alike as an excellent contemporary source book.

And we suggest, if you are not familiar with this latest of GM publications, that you check your college library.

But—this is not a "circulation advertisement" for the *Journal*.

We mention it here—because we think a glance through any issue will give you a pretty clear picture of the high standards and advanced viewpoints of our GM engineers. And of the intellectual climate they find in which to think and to work at GM.

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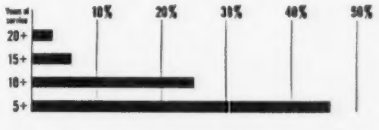
These growing programs mean expanding opportunities at Boeing for engineers of virtually EVERY type, including mechanical, civil, electrical and aeronautical. It also means plenty of room for advancement. Boeing, which now employs more engineers than even at the peak of World War II, promotes from within, and holds regular merit reviews to give you individual recognition.



As the chart shows, 46% of Boeing's engineers have been here for five years or more; 25% for 10 years; and 6% for 15 years, and many have been with the company 25 years or longer.

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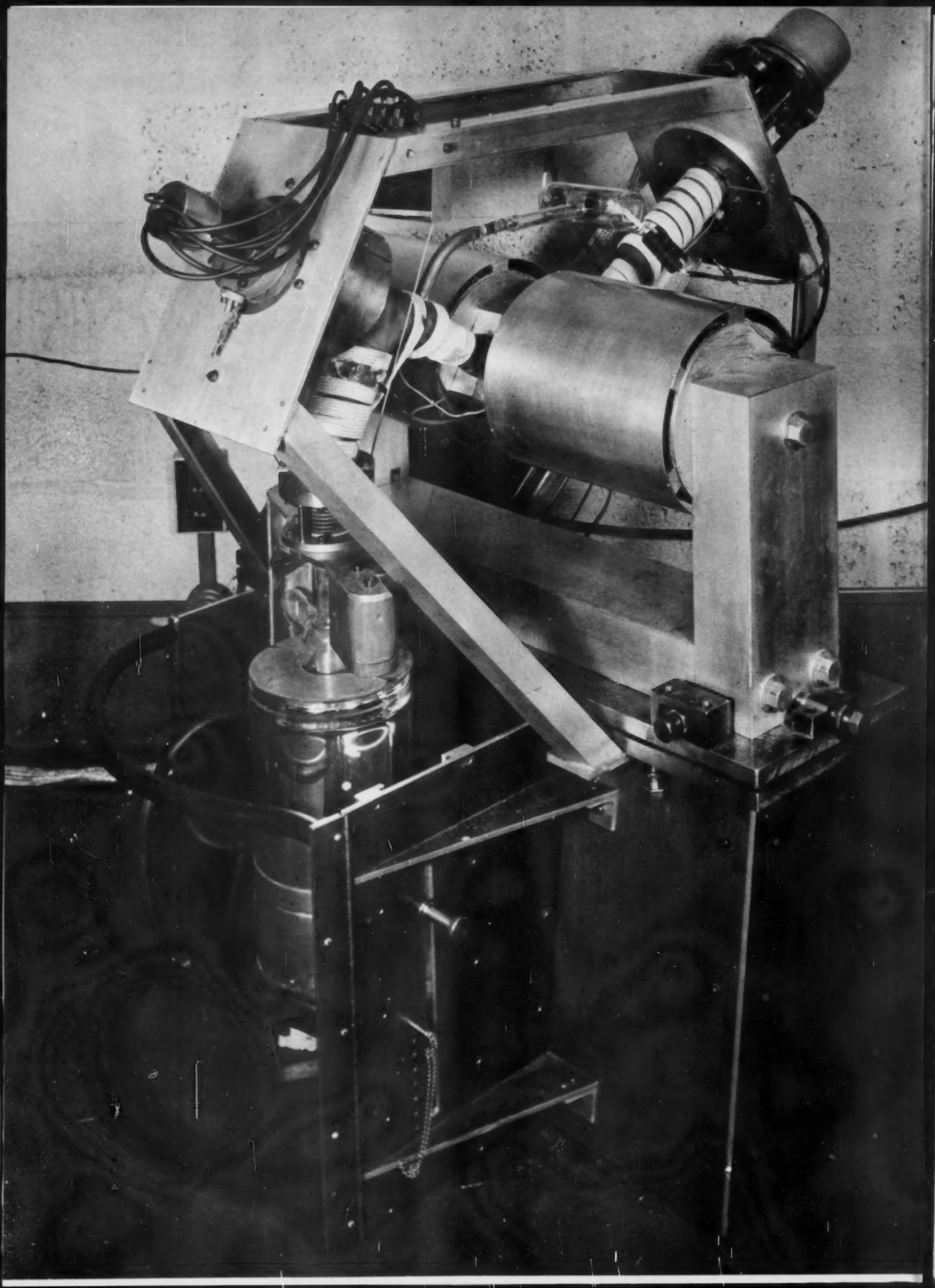

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Mass Spectrometer

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A MESSAGE TO
COLLEGE ENGINEERING
STUDENTS

from J. M. Wallace, Manager, Meter Div.,
Westinghouse Electric Corporation
University of Pittsburgh, 1935

To the man who wants more than a job

You and I know that getting a job is not a problem these days. Industry needs thousands of young engineers.

But the man who wants more than a job might well pause and consider just how he is going to find his special opportunity. It cannot be found everywhere.

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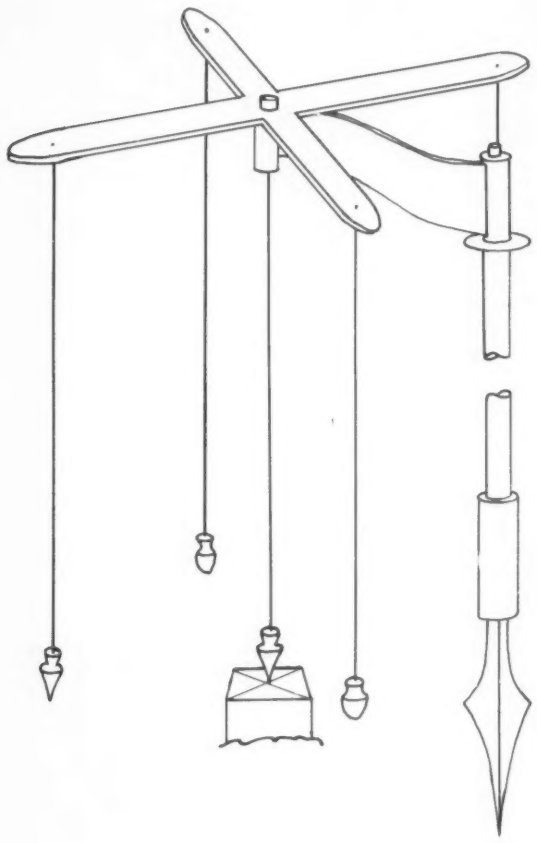
gromatici erant

A discussion of Roman surveying instruments

By James Simmords, '57

Surveyors are first mentioned in Roman history in connection with the construction of the military camps of Antony. The Romans were interested in the practical applications of surveying to engineering projects and military operations, and therefore it is not surprising that we later find technical schools established for the purpose of training Roman surveyors (*Gromatici* or *Agrimensores* as they were called). Even a "graduate course" was given to those who wished to specialize in property surveying. The Roman surveyor, however, was no better than his instruments; these, despite their crude appearance, often produced amazingly accurate results. The magnificent Roman aqueducts, roads, and bridges all attest to this.

Fig. 1. The Groma



In Julius Caesar's time Beta, rather than Polarius (Alpha of Ursa Minor), was the pole star. Polarius then was some ten degrees farther from the celestial pole than it is at present. Being a star of somewhat lesser magnitude than Polarius, Beta was very difficult to observe; hence solar observations were almost exclusively used to determine the true meridian. For this purpose two devices were used: the *Horologium* or sun dial and the *Gromon* or pole. Since the *Horologium* was a more or less permanent affair, it could not be effectively used as a surveying instrument. Instead the *Gromon* was used to find the meridian. This was done as follows: On a large, flat surface a circle was described. At the center of the circle the *Gromon*, a tall pointed pole, was placed vertically in the ground. In the morning a point was marked on the circumference of the circle where the shadow of the top of the pole first crossed it. In the afternoon another point was again marked where the shadow of the top of the pole recrossed the circumference. These two points were joined by a line. Another line was drawn from the base of the *Gromon* bisecting the first line. This second line was then the *Kardo*, or principal meridian of the survey. At right angles to the *Kardo* the *Decumani*, or east-west "base" lines, were laid off. Of course it must be realized that the true north-south meridian could only be determined on the days of the vernal and autumnal equinoxes.

To measure distances along rough or sloping ground the Romans used the *Pertica* or *Decempeda*. This was a wooded pole about ten feet long with two metal ends. Plumb bobs, similar to those used by surveyors today, were used with the *Pertica* to mark the distances along the ground. The *Pertica* was also used as a range pole. On open level ground specially treated ropes were used to measure distance. According to Hero of Alexandria the ropes were prepared by alternately stretching them taut between two stakes and rubbing them with a mixture of beeswax and resin. William M. Gellespie (*A Treatise on Surveying*) states that these ropes, when properly treated, will not vary by more than one part in two thousand from a gunther's chain.

For measuring long distances along a road or highway a machine known as a hodometer was used. The forerunner of the odometer, it was a Rube Goldberg-like device which, through a series of wooded gears and pegs, dropped marbles at regular intervals into a bucket. Thus one measured the distance traveled by the number of marbles

in the bucket. Both Hero and Vitruvius give complete instructions for its construction.

The *Groma* and the *Dioptra* (figures 1 and 2) were both used to lay off horizontal angles. Actually the *Groma* could be used only for turning right angles unless, of course, the cross piece which held the plumb lines was changed. The exact appearance of the *Groma* was very doubtful until 1912 when the ruins of a Roman surveyor's office, with much of the equipment still intact, were uncovered at Pompeii. The *Groma* consisted of four parts: the cross or Groma proper which was about three feet across; four plummets suspended from the cross, two of which were plumb bobs and two of which were weights; a swinging arm which, with the cross and plummets, could be removed, and a "Jacob's staff" with a pointed iron shoe at one end. Another plumb bob which could be used to orient the instrument over a monument hung from the swinging arm, directly below the center of the cross. The *Groma* was very similar to the surveyor's cross used in the 19th Century, the main difference being that on the surveyor's cross vertical slits mounted upon the cross were used to sight by instead of vertical plumb lines. To use the *Groma* the surveyor first set it over some monument or other marker, but with the Jacob's staff

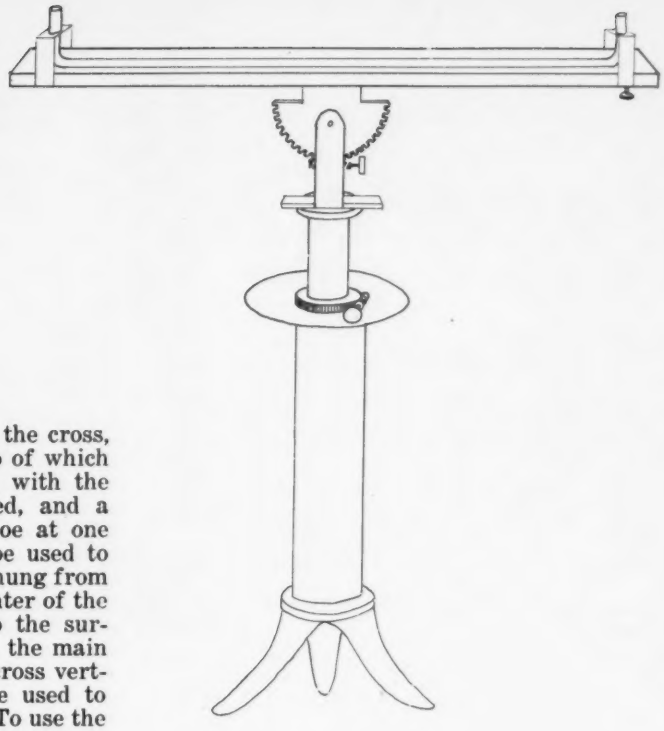
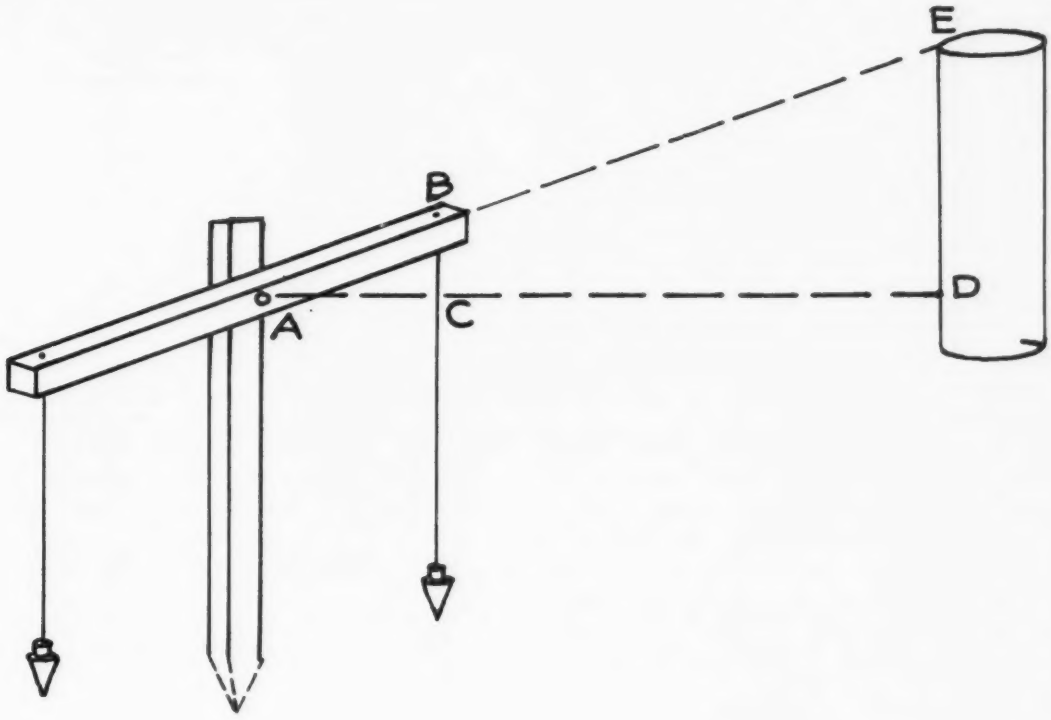


Fig. 2. The Dioptra

Fig. 3. The Lychina



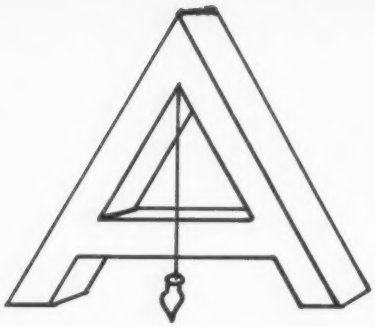


Fig. 4A. The Libella

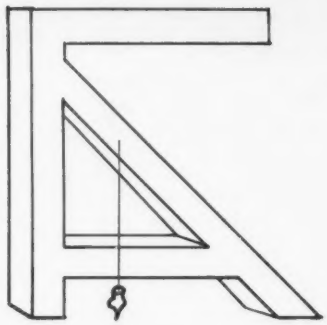


Fig. 4B. The Norma

not on any base line. Then two strings on the same arm were lined up with a backsight, and a foresight was set. By sighting down the strings of the other arm of the cross, lines at right angles could be established. Hero warns that great care must be taken in using this instrument. He says that the plumb lines must be made to hang vertically (especially hard to do in a strong wind) and that the cross of the *Groma* must be made perfectly level.

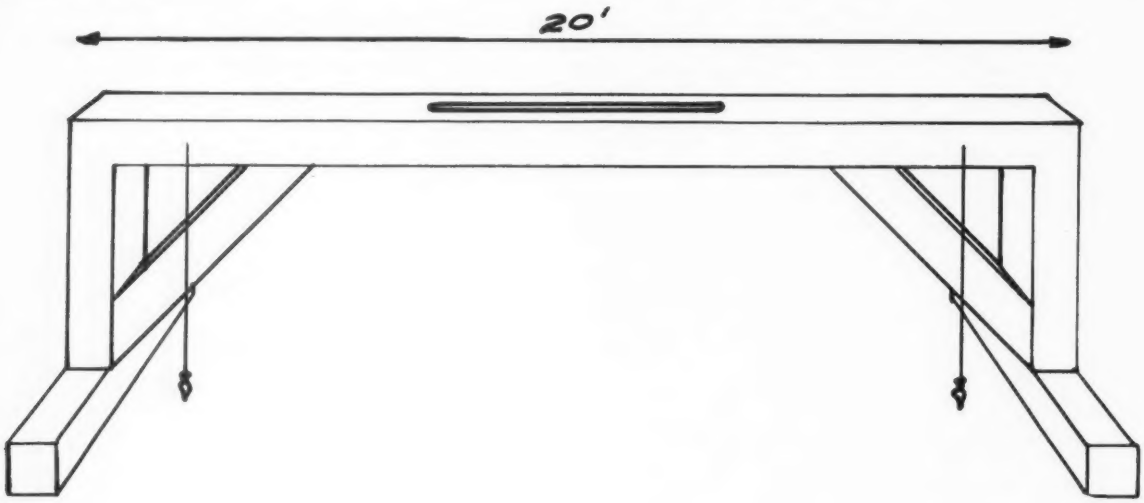
The *Dioptra* was a Greek invention, but it was used extensively by the Romans. A versatile instrument, it could be used both for leveling and for measuring horizontal and vertical angles. Its operation is obvious from the drawing. Leveling was done by sighting through an adjustable slit along the top of the water in the two ends of the glass tube which ran along the top of the instrument. The leveling tube could be removed from the base, and an angle reading attachment put on.

Due to its simple construction the *Lychina* was probably used before the *Dioptra* to measure vertical angles (fig. 3). The distances AD, AC, and BD could be measured. Then by similar triangles the vertical distance DE could be computed. It is evident that the instrument was not too accurate.

Two types of instruments were used for leveling: those using plumb lines, and those using water levels. The *Chorobates* was an instrument employing both of these methods. (Fig. 5). Normally the two plumb lines at either end of the instrument were used to level it, but on windy days a water trough about five feet long in the center piece of the apparatus was used. The *Chorobates* was more accurate than the *Dioptra*, but more troublesome to use. The *Norma* and the *Libella* (Fig. 4), two similar instruments, were leveled by plumb lines. When the plumb line of the *Libella* exactly coincided with a mark in the center of the cross-piece, the instrument was level. The *Libella* had the same shape as the modern miner's triangle, and it is interesting to note that the Forty-niners in California set up hundreds of miles of ditches and grade stakes with this same type of instrument. A target rod was used in conjunction with these leveling instruments. The target was raised or lowered by the rodman by means of a string placed over a pulley and attached to the target. A pointer fixed to the target enabled the rodman to read elevations directly from a scale on the side of the rod. Leveling was done the same way it is today. The sum of the foresights was subtracted from the sum of the backsights to give the difference in elevations from a fixed bench mark.

As mentioned before the accuracy attained with these simple instruments was extremely good. On an 80 kilometer line from the district of Walldurn in Boden to Wurtenburg, a recent survey has revealed that the Roman surveyors were at no point more than two meters off the true line.

Fig. 5. The Chorobates



James B. Walker received his B.S. in mechanical engineering from North Carolina State College in June 1954, and he's presently working for his M.S. at the same college. By asking pertinent questions, Jim is making sure that the position he finally accepts will be the right one for a fellow with his training.

Jim Walker asks:

Can a mechanical engineer make real progress in a chemical firm?

H. M. Pickering, Jr., received a B.S. in M.E. and E.E. from the Univ. of Minn. in 1940. He gained valuable technical experience at Hanford Works, in Richland, Washington, and in Du Pont's Fabrics and Finishes Plant at Parlin, N. J. Today he is Works Engineer for Du Pont's Seaford, Del., plant, where nylon comes from.

"Pick" Pickering answers:

Well, Jim, that's what the lawyers call a leading question, and the answer leads right into my bailiwick. I came to Du Pont in 1940, after taking a combined mechanical and electrical engineering course. So I had what you might call a double reason for wondering about my future with a chemical firm.

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My own Du Pont experience includes mechanical engineering work in fields as varied as atomic energy, fabrics and finishes, and nylon manufacture. Every one of these brought with it a new set of challenging problems in construction, instrumentation, and power supply; and every one provided the sort of opportunities a man gets in a pioneering industry.

So, to answer your question, Jim, a mechanical engineer certainly has plenty of chances to get somewhere with a chemical company like Du Pont!

Want to know more about working with Du Pont? Send for a free copy of "Mechanical Engineers at Du Pont." This 24-page booklet describes in detail the four broad categories of jobs mentioned by "Pick" Pickering. Typical pioneering problems in each of these four categories are outlined. This booklet briefs a young mechanical engineer on how some of the newest and most challenging problems in his field were solved. Write to E. I. du Pont de Nemours & Co. (Inc.), 2521 Nemours Bldg., Wilmington, Del.

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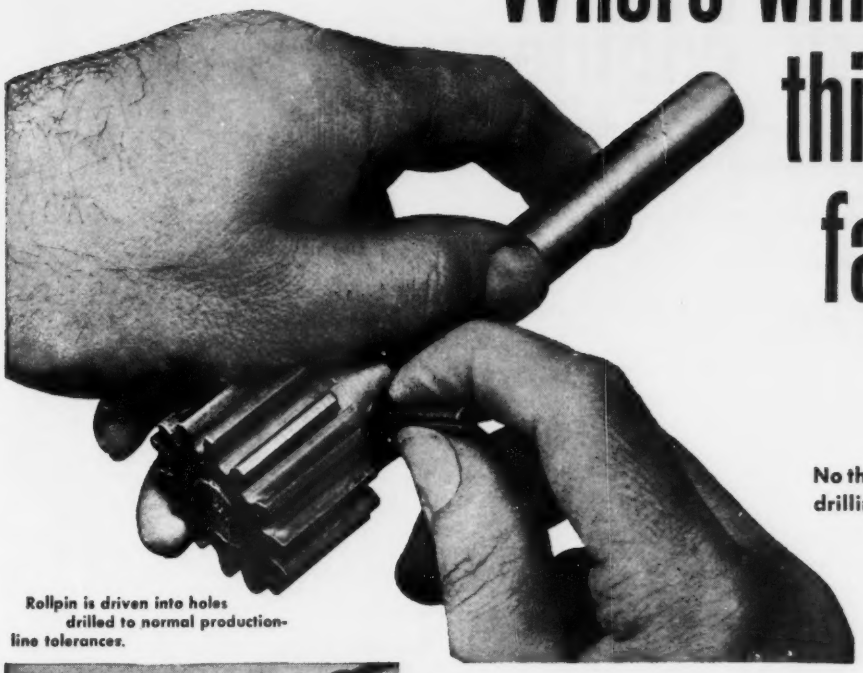

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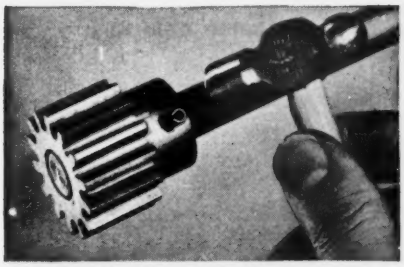

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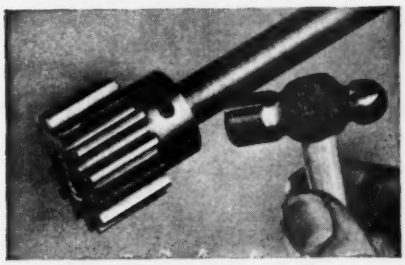

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from the editor's notebook

Very recently there appeared an editorial in the "Princeton Engineer" condemning the staging of an intercollegiate convention by students only. The editor said: "Their failure was . . . due to . . . the absence of occasional advice and positive guidance from their tutors." Another point made was that the freedom of the students and the little time the instructors have to give to the students adds up to a "factory" education with no real relationship between the students and the faculty.

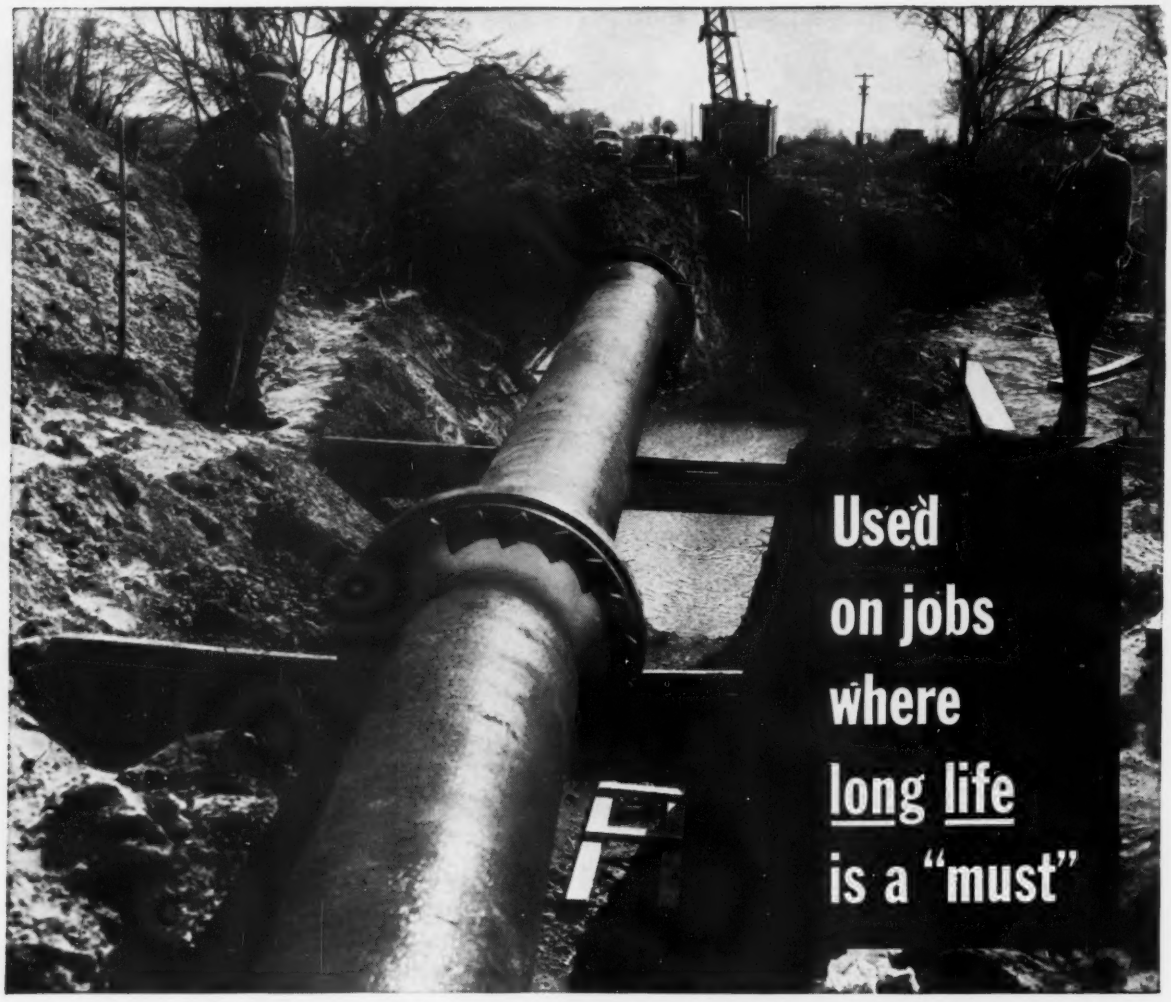
We must concede that the students involved did muff the job but the essential fact is that the students did do the whole job. In the future we can look for better conventions being presented by the students *alone*. The importance of this step toward complete student management of affairs dealing with students and faculty members of other colleges cannot be overly stressed. There is no longer the crutch of too little advice to fall back upon, as other colleges have. We do not condemn occasional advice *when asked* but positive guidance could keep the students from thinking for themselves.

This positive guidance, or faculty "interference," very possibly stems from the fear of a loss or degradation of the reputation of a school or department because of student bungling. When a school or department has enough courage to give the students full control of conventions and other activities dealing with outsiders, the attitude of this school or department has grown into more than a mere "relationship"; it has grown rather into a pride and faith in the quality of their students.

"Administration can only provide the conditions favorable to closer ties." But is there not another provision that the administration can make? Yes! The provision of trust; far greater than advice, talks, and social gatherings is this faith in the students. "Experience is the best teacher" is still true. You would think from the emphasis on freedom of the students and student bungling that the students might never learn to fend for themselves. Do not forget that the students running these affairs will pass on their experiences to younger students and will — while working — gain much-needed self-confidence.

We must admit that Princeton's preceptorial system would be desirable here at the Institute. We cannot admit, however, that to compensate for the large number of students we have had to lower the quality of the students. With the combining of courses and the giving of advanced courses earlier in the students' training, we may say that if anything the quality of the students has increased. May we also venture to say that one of the reasons for this is the better chance to mature because of less interference and more guidance from the faculty. This guidance that gives us all this "freedom" is often misinterpreted by outsiders as a reluctance to advise and fear of repulsion if there is advice given. I am sure that there are few instructors at the Institute who would not give of their time for advice and instruction if asked. It is for the students to ask the instructor's advice and in this point I agree with the Princeton editor when he wrote: ". . . students . . . have made so little effort to know their faculty."

H. I. S.



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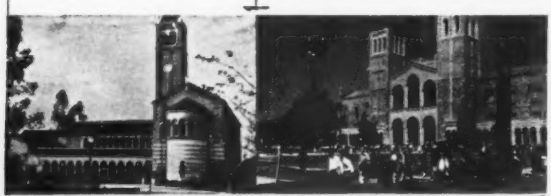

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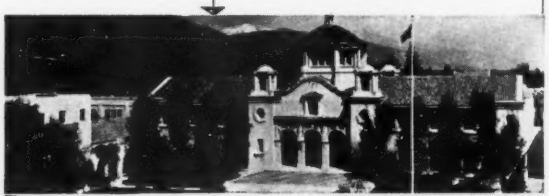

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limitations of math reasoning

On the limitations of mathematical reasoning

by Barry Mazur, '58

Mathematics is a pervasive subject. All knowledge becomes embraced by it. But it has its limitations as well.

What is mathematics anyway? Its beauty and elegance have enchanted many people and yet the essence of mathematics does not lie in the sphere of aesthetics. It is relied upon faithfully as the tool of those who seek to understand basic physical relationships and yet its domain need not touch upon the physical. Is it true that its doctrines are irrefutable?

To answer these questions, or at least to attempt at an answer requires that we recall the basic formulations of a system of mathematics.

Mathematics, I maintain, is pre-eminently a structure of knowledge and owes all properties to that fact. Therefore to understand the formulation of such a structure of knowledge we must first investigate the properties of knowledge as such. Our answer to the question, "what is mathematics?" is then contingent upon the answer we arrive at to the question, "what is knowledge?"

There exists in the universe around us two forms of basic knowledge, according to Kant. The first constitutes the form of knowledge that must be experienced to be actually known. Therein lies the realm of physical knowledge. When you demonstrate to me the fact that the voltage in a direct current circuit is in direct proportion to the current flow through it, then and only then will I accept it as knowledge. I accept it with the mental reservation that I may withdraw it from my storehouse of true knowledge if at any time it fails to be borne out by physical facts. Indeed, if we investigate this matter more thoroughly we find that the voltage and current which we just hooked up according to the aforementioned relation are themselves mere concepts; they are merely attempts to visualize this knowledge. The question arises, are voltage and current themselves knowledge in the same category that we have admitted the relationship which binds the two to be.

Well, says Kant, the knowledge of the relationship between two concepts we may call *a posteriori*. This is obtained through experience and only through experience. The method for formulation of *a posteriori* is of course inductive and all such knowledge lies beyond the realm of deduction. However, continues Kant, there exists a more formidable body of knowledge—knowledge that may be inferred without the benefit of experience, so-called intuitive knowledge. This he terms *a priori*.

Modern philosophers object vehemently at the mention of knowledge obtained without the aid of perception. They hold that all knowledge is arrived at through experience with the outside world. This view has been substantiated by the fact that many things once held intuitively obvious are now known to be false.

Does this prove the non-existence of *a priori* knowledge? I submit that it does not. When, through experimentation, we find that in physical reality there exist such discrete particles as may be persuaded to flow through a metallic conductor, under certain conditions, and furthermore, that a property may be attributed to such a flow—namely, rate of flow, we can postulate the existence of such a concept. That concept is current and I maintain that wherever there exists such a flow, there exists a numerical quantity which may be associated with the concept of current.

The knowledge of current, I further maintain, is *a priori*. It is *a priori* in that there need not exist such discrete particles at all for the concept of current to exist. The concept exists over and above experience, because I have defined it so. No amount of experimentation can possibly disprove the existence of that concept.

Moreover, there are two categories of existence which we must contend with. To confuse physical, or concrete existence, with the existence characterized by the world of ideas would be disastrous. When I speak of physical existence, I refer to anything which may be perceived and am using the word with its Berkleyan connotations. When I speak of a concept having existence, however, I mean something more definite. A concept exists only if it may be derived directly from something we have previously defined, or postulated. Consequently, all concepts that are defined exist!

Returning to current and voltage, we see that it follows from our use of the term "existence" that they *must* exist. Their existence is not contingent upon whether those discrete particles to which the concept applies exists physically. For indeed, if all knowledge of those concepts not affected at all by experience, if experience need not logically give rise to those concepts, and if experience cannot conceivably contribute to the disproving of those concepts, then it follows that in the strict Kantian sense, there does exist a body of knowledge entirely aloof from any attachments with "reality."

Also, it is seen that all physical knowledge is obtained through the medium of experimentation and must therefore be classified as *a posteriori*. A curious fact, however, is that concepts must necessarily be introduced to physically explain this knowledge. It is necessary, if we are ever to obtain any simple way of visualizing the processes of physics, that it be explained in terms of strictly definable concepts. It turns out, therefore, that rather than there being only *a posteriori* knowledge, all *a posteriori* knowledge must have its roots, its foundations, in *a priori* knowledge.

Obviously this result is borne out in our ex-

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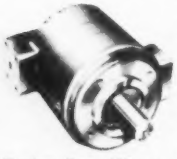

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ample. The fact that there is a proportional relationship is *a posteriori*. That relationship however, is a relationship between two concepts, the knowledge of which is *a priori*.

From our discussion, it then appears that the realm of mathematics extends to all *a priori* knowledge. In other words the substance of mathematics is definitions and axioms. In the words of Bertrand Russell, "Pure mathematics is 'a' implies 'b'."

Is every mathematical truth a tautology? If I create a mathematical system of knowledge, which I will denote as S, consisting of a set of postulated and defined propositions, P_1, P_2, P_3 . . . and if I find as a direct consequence, a proposition P^1, not contained in the set of propositions, P, is true, then from our previous discussion we know that the knowledge that P^1 is true is *a priori*. Does it necessarily follow that P^1 is true in another system of knowledge, S^1? Obviously it does not. Therefore it is necessary to qualify *a priori* knowledge and attribute it to a specific system. In other words, a correct statement would be P^1 is true in S, or to use Russell's terminology, S implies P^1. The statement that S implies P means exactly this: The proposition P is inherent and it is contained in the proposition S.

We are now forced to answer in the affirmative. Yes, mathematics is a tautology; moreover all intuitive knowledge appears to be tautologic. To a Laplacian superman (an intellect which is assumed to have all possible information at its command) all intuitive knowledge will be mere trivia. Indeed, all mathematical truth, no matter how wonderous and startling it may appear to be, would be reduced to the trivial statement that "X" is equal to "X", to this infinite intellect. At first this may sound as a serious limitation, but reflection will bear it out as a necessity. The pure process of reason *should* not get out of a statement anything more than what is put in. All that reasoning process should do is to clarify exactly what is inherent in a statement (or group of statements).

The well-known Heisenberg Uncertainty Principle provides an interesting illustration. It states the seemingly amazing mathematical deduction that the more certain we are of a particle's position, the less certain we are of its velocity and vice versa. If we observe that it would be impossible to perceive the electron without radically altering either its position or its speed (in most instances both), then the principle *must* follow. The principle is interesting in that nowhere did Heisenberg ever deal explicitly with the phenomenon of perceiving electrons. However, if he came to any other conclusion than the one to which he did, we would not be able to test whether it was so, precisely because we cannot perceive electrons with any accuracy. Moreover, it would raise some serious philosophical problems as to how and where the data determining the position and velocity of electrons managed to creep into his equations since we can't seem to determine those quantities experimentally, and, after all, Heisenberg's physics was formulated on the basis of experimental facts. As it stands, his theory raises enough serious philosophical problems.

The statement that S implies P means that given a system S, the consequences of such a system, P^1, P^{11}, . . . are mere tautologies, with no profound philosophical truth other than identity. Wherein then, lies the beauty of mathematics? What ultimate good may be derived from a study of it? Where does creativity enter into it?

The province of mathematics, I believe, is in notation. There is where creativity lies. I believe that is the essence of the subject. It is the main goal of mathematicians to express greater and greater complexities of ideas with simpler and simpler notations. It is to view the complex in new ways, always in a different light, so as to obtain different and broader sweeping consequences. It is the "experimental laboratory" of *a priori* knowledge. The beauties and deep philosophies which can emerge are due to the multifarious patterns of logical thought with which the subject abounds.

The most thought-provoking definition of mathematics that I have ever heard was the one given by Professor Whitehead when he said that mathematics is the science of pattern.

A deep, almost religiously fervent belief that the richest philosophical or physical concept can be expressed with elegant simplicity and still retain all of its ramifications is fostered in the

mathematician. The field of mathematics looks toward notation for more fruitful avenues of intellectual endeavor. By notation, of course, I include defined concepts, such as groups, fields, rings, etc. I mentioned above, the concept of existence of ideas and "objects". I should now like to investigate exactly how the definition of existence of concepts applies, with respect to mathematical concepts in particular. Does mathematical existence imply some corresponding physical existence?

Let us take a simple propositional function:

$$1 + 1 = x$$

Now one may say that there exists a number such that it would reduce the above function to a true proposition, i.e., when x takes the value of 2. What about corporeal existence? Need it necessarily follow, that, were we to take one object and another object we would always end up with two objects? Well, it may be true. Its truth, however, lies only in the sphere of *a posteriori* reasoning. It follows then that there are many answers to the propositional function. As was noted before, the answer you get depends upon the system of propositions you accept beforehand. Were I to accept the ordinary propositions of arithmetic, the value of x that would satisfy the expression would be 2. Were I to treat it in a system where I have previously defined the operation to mean that I should take the two numbers and measure their length on the arc of a circle, then take as my answer the length of the corresponding chord, there are an infinite number of values of x that could possibly produce a true proposition of that function. In particular, x could be anything greater than or equal to zero and less than two.

Even if I define the binary operation (+) as the addition of two equal lengths of unit magnitude marked off on some standard rigid object in our universe, there are still an infinite number of values of x which exist that make 1 + 1 = x a true proposition. In particular, x has a range of values: 2—e x 2+e, where 2e is the possible experimental error involved in measurement. Obviously, then, there is no exact correlation that one may make between the existence of a number in the mathematical realm, and the existence of a number in the physical realm. Keeping that fact in mind, I should like to pose the following problem:

Assume that we have a certain universe, a closed system. I will allow one governing postulate of this universe. That is that there is no correspondence with irrational numbers *whatsoever* in the system. The existence of irrational numbers would lead to some logical inconsistency. That means that such points in the space of this universe, as might correspond to a dyadic number relationship where one of the pair of numbers is irrational, do not exist. It means that any quantitative measurement in the system can be expressed exactly in terms of rational numbers, assuming that the range of error is zero. The question of whether or not a system, such as the one I just described, can possibly *exist* will be dealt with later.

Now I shall take the series:

$$a_0 + \frac{a_1}{10} + \frac{a_2}{10} + \cdots + \frac{a_n}{10^n} + \cdots$$

and attribute values to the a's in accordance with certain happenings in this universe. Suppose that I take a coin in this universe and define the a's as follows: I shall repeatedly flip the coin and record the results. If, on the first flip, the coin landed on heads, I shall define a_0 to be zero. If it landed on tails, it is defined to be zero. A_1 is defined similarly for the second flip of the coin, and similarly for all the rest of the a's. In other words, the number which can be expressed as a continuous decimal:

$$a_0, a_1, a_2, \ldots a_n \ldots$$

is, in a manner of speaking, the history of the flips of this coin. Now it can be proven that any repeating continuous decimal is rational, and any non-repeating continuous decimal is irrational. Obvi-

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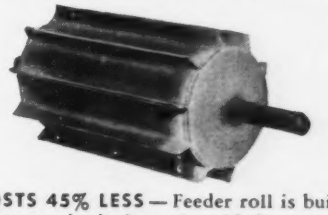

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ously, if we are to maintain our postulate which governs this universe, the continuous decimal which we shall denote by D that is obtained in this manner, must be repeating. That, however, requires the coin to flip in finite repeating sequences. We might apply this type of reasoning to any happening in this universe. To uphold our primary postulate, then, it is necessary for all events that occur in this universe, to occur in cycles. The problem I shall pose is this: *is* it necessary for all events in this universe to occur cyclically? First we must answer some objections that may arise against the validity of my previous argument. Someone may object that D is not irrational, because its being irrational presupposes that we can flip it an infinite number of times. The fact is, of course, that we cannot flip it an infinite number of times. To rectify that shortcoming in my argument, I submit that a decimal D^1 may be associated with some continuously occurring phenomenon, and if one supposes that this universe (if it exists at all), will exist for an infinitely long duration, and, if we take periodic readings of this phenomenon, we will have an infinite number of readings; hence, an infinite number of terms for D^1.

For example, if there exists any concept in that universe corresponding to a quantitative variant, such as mass in our universe, we may ascribe to D^1 periodic readings of that variant, such as total mass at certain times, and obtain an infinite decimal in that manner. This assumes that there are fluctuations in that universe. It assumes that there exist in that universe such objects that will lead towards change.

The next and more important objection to this reasoning is that I assume the possible existence of such a universe. Unfortunately, it is an objection which I cannot dispose of as easily as the first.

Reverting to the earlier discussion of existence, I should like the reader to recall my two definitions of the term. At this point I should also like to define the concept "possible". I shall use "possible" in the Leibnitzian sense. In other words, a set-up is possible physically, if there is incurred no logical inconsistency by our assuming that it exists. By our definition, it follows directly anything that is possible conceptually, is possible physically.

Hence to show that the existence of such a system is not impossible (so as to remove the objection) I must show that there is not incurred an inconsistency by believing it to exist. I regret to admit that I cannot do so. And the sadder part of it is that it cannot be proven of any system. I take refuge in the fact that all of mathematics stands on as flimsy ground as my system. Euclid's geometry, regardless of the fact that it has existed for hundreds of years, is not free from that objection.

And here we come to the first important limitation of the validity of mathematics, and mathematical systems. Almost all of the ramifications of a mathematical system may be examined. Almost all of its consequences can be proven, at least mathematicians are instilled with that belief. There is one thing that cannot be proven, however, and it is that the system *is possible!*

It is easy to see why that situation is so. To prove a system impossible, we must show that one of its consequences is "A", and another of its consequences is "not A". That follows from the definition we accepted for the term "possible". To prove that a system is possible, therefore, it is necessary that we prove conclusively and rigorously that there will never be two consequences of the system such that one is "A", and the other is "not A". That requires that we examine every single consequence of the system S. It is impossible to do so, and what is more, even if we are able to do so, no method has yet evolved whereby we can prove conclusively that we have done so.

The property that a system of postulates is said to have, if they lead to something which is possible, is called "compatibility." Although we can be reasonably certain in the compatibility of Reimannian Geoemtry or Hilbert's Doctrinal System, or other propositional systems, we can never erase all elements of "Cartesian" doubt, as to the possibility of such a system. Indeed, some mathematician in the future may unearth a self-contradiction in those geometries, rendering them incompatible and hence false.

The idea of incompatibility between two or more propositions in the same system is not peculiar to the subject of mathematics. All doctrines must be compatible within themselves in order for any of their consequences to be borne out. Karl Marx occupied a good part of his life by analyzing the propositions implied by the economic system of nineteenth century capitalism and attempted to prove it self-contradictory—and he did. His analysis of capitalism was such that it lent itself to concise formulation in terms of a propositional system. His logic was nothing short of mathematically rigorous from then on in proving that such a system would not work effectively for any period of time.

There are many branches of knowledge which can be reduced to the beautiful simplicity of a mathematical system. In fact, the entire field of thermodynamics can be considered a geometry of the sort that we are discussing. Its principal laws can be considered propositions, in which case, all of its consequences are directly implied by them. We may say that the truths of thermodynamics are valid wherever the first and second laws hold, and in that sense have equal status to mathematical truths.

All philosophical systems are of course in this category and should be continuously scrutinized as to whether they are inconsistent. We should ask ourselves whether our own thoughts are inconsistent. Do we take things for granted which would prove under more scrupulous observation to be self-contradictory?

It is a question which we should never *stop* asking ourselves because we can never answer it with a definite no!

We are now prepared to tackle the problem of whether or not the truths of mathematics are irrefutable . . . unfortunately they are not. We have shown previously that the province of mathematics is tautology and can be considered as: S implies P. However we have just shown that we can never be certain that S is possible. Of course, if S is impossible, we cannot draw any valid conclusions from it, so therefore we must narrow the domain of mathematics still further. We must now say that S implies P only if P is possible.

It follows then that mathematical truth, and hence the validity of all reasoning is by no means irrefutable; it can never be.

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the incandescent lamp

by Rae Frank Stien

1954 marks the 75th anniversary of Edison's invention of the first practical incandescent lamp. Since that time 39,500,000,000 electric lamps have been produced in this country alone. As many more will be produced in the next 15 years.

Fundamentally, an incandescent lamp is a simple thing—just a wire sealed in a glass bulb with a few supplementary parts. The power required to force electric current through the filament heats it to incandescence, and light is thus produced. It is necessary to heat the filament to 5000 F., yet the filament does not burn up because it is either in a vacuum or an atmosphere of inert gas.

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Theoretically, a tungsten bar at its melting

point would yield an efficiency of 52 lumens per watt; however, the highest practical efficiency at present is 35.8 L/W for incandescent lamps. The reason that bulbs are not operated at the maximum theoretical efficiency is that as the temperature of a filament is raised to increase its efficiency, its life is shortened because it vaporizes more rapidly. Obviously, a tungsten lamp could be operated at 52 L/W only until the filament melted. In order to determine the most practical lamp for a particular application one must consider not only efficiency, but also lamp life.

Cost of Producing Light:

One buys lamps for their qualities of producing light economically. It would be possible to produce a lamp that would last 3000 hours; however, this lamp would not be economical, for it would be very inefficient. When we make a "cost of light" calculation we must consider the cost of the bulb, its life, its efficiency, and the cost of electricity. The formula for the unit cost of light is as follows:

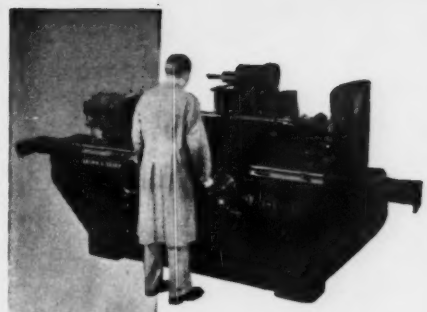
cost per million lumen hours in dollars

$$= \frac{10}{E}\left(\frac{P}{WL} + R\right)$$

E—Average lumens per watt throughout life
W—Average watts throughout life
L—Average lamp life in thousands of hours
P—Net cost of lamp in cents
R—Cost of electricity in cents per kilowatt-hour
One million lumen hours is used as the unit in cost of light calculations because it is equal to the total light produced by a 100 watt lamp when operated at normal voltage.

An interesting application of the cost formula is that it is common practice in floodlighting of baseball, football, and other recreation areas to burn lamps 10% above rated voltage. This results in 35% more light for 16% more wattage. The average lamp life is decreased to between 200 and 300 hours or usually representing at least one full season's use. In the above example the shortened life of the bulbs is more than compensated for by their increased efficiency.

Lamp economies in many installations involves in addition to the cost of light, the cost and inconvenience of replacement and/or handling. This is important in certain classes of service: mainly street lighting, large stores and offices, signs, etc. In these instances lighting service can be improved and the actual cost of producing light might be decreased by replacing all the lamps in a group at some fraction of the average life. At 90% of life, 72% of the lamps are burning; at 80%, 84% remain. Replacement at 70% average



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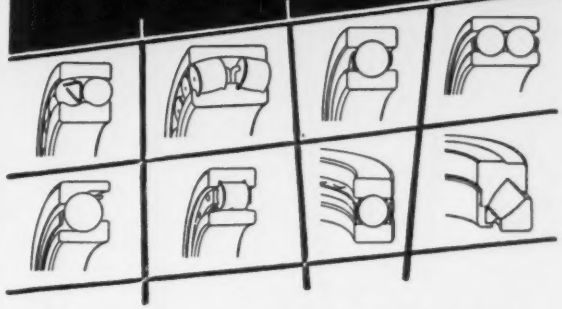

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The 40 hour watch on the first practical incandescent lamp.

life is oftentimes adopted as the economical point for group replacement, for at this point less than ten per cent of the lamps should have failed.

Lamp life is necessarily based on averages obtained from life-testing hundreds of thousands of lamps annually. A perfect "mortality" record would be one in which all the lamps tested reached 100% rated life and then burned out. Ratings are usually calculated for the time when about 50% of the lamps have burned out. Between 60 and 100% rated life is the area in which it is most economical to replace a lamp, whether it is burned out or not. Operating a lamp beyond 100% life is definitely not practical.

The first lamp burned for 40 hours. During this time Edison and his co-workers carried on what was later known as the "death watch." Certain that they were on the trail of success, they increased the voltage and deliberately burned out the lamp. The lamp was of 110 watt size and had an efficiency of 1.4 lumens per watt.

The incandescent lamp bulbs that we use today are, in principle, exactly like Edison's bulb of 1878. The only major changes have been the substitution of tungsten for carbon in 1906, and the introduction of the gas-filled bulb in 1913. Other developments that increased lamp efficiency were the double coiling the filament wire, removing the exhaust tip from the bulb, reducing the blackening of the bulb, and the use of mass production methods.

The theoretical maximum efficiency for conversion of electricity to light is 220 lumens per watt for white light. The most efficient flourescent lamps have an efficiency of 69 L/W. Much work is being carried on to provide more efficient lamps and the future should see some interesting new lamps with much higher efficiency than the maximum at persent.

TABLE I

Table of Commercial 100 Watt Lamps

Lamp type, voltage, and service	Efficiency, L/W	Life, Hours
240 volt vacuum	9.9	1000
120 volt vacuum	11.3	1000
120 volt rough service	12.0	1000
240 volt general lighting	12.4	1000
120 volt general lighting	15.4	1000
60 volt train lighting	16.5	1000
120 volt general lighting	16.3	750
20 volt train lighting	18.5	1000
120 volt projection	19.2	50
12 volt aviation	22.0	100

courtesy of the General Electric Co.

tonight

This man could almost reach the moon tonight... for he stands at the brink of a new age in the conquest of space, and he knows this:

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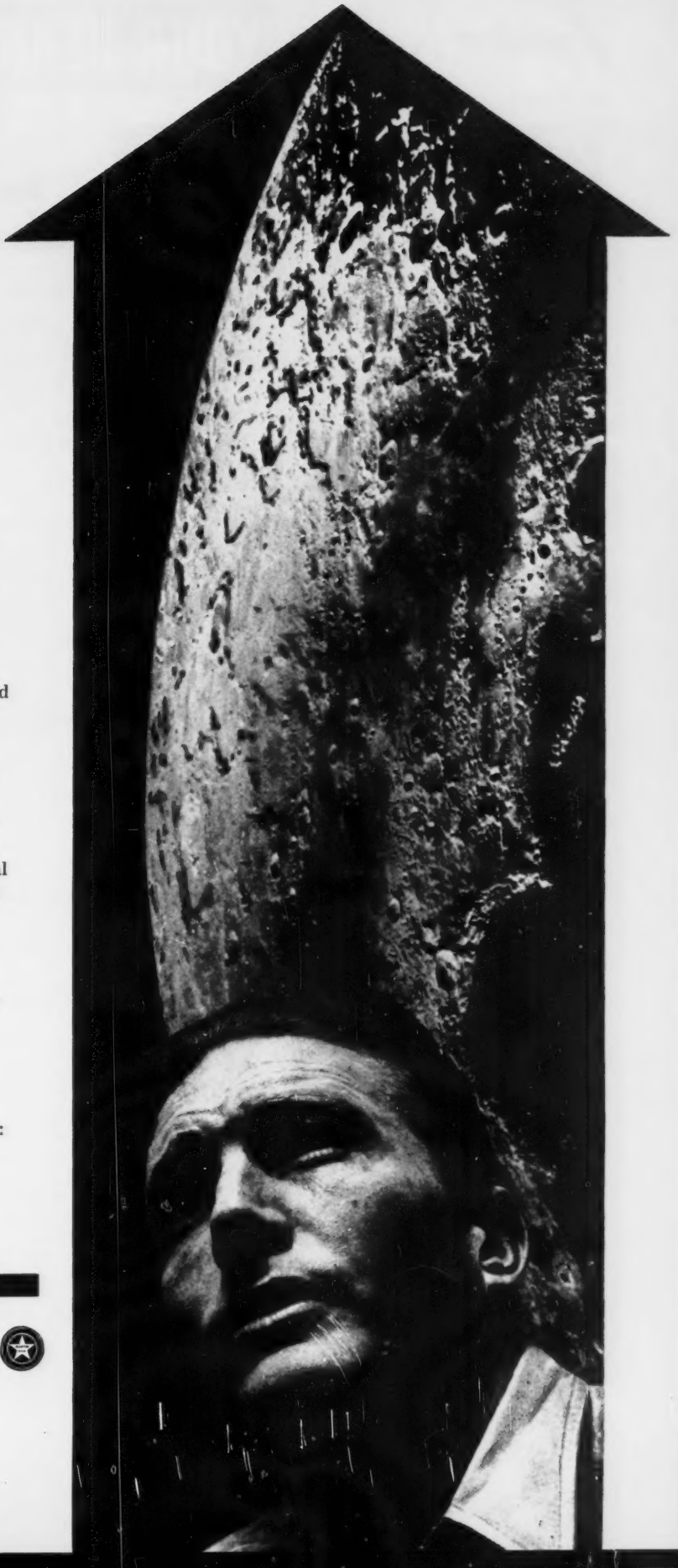

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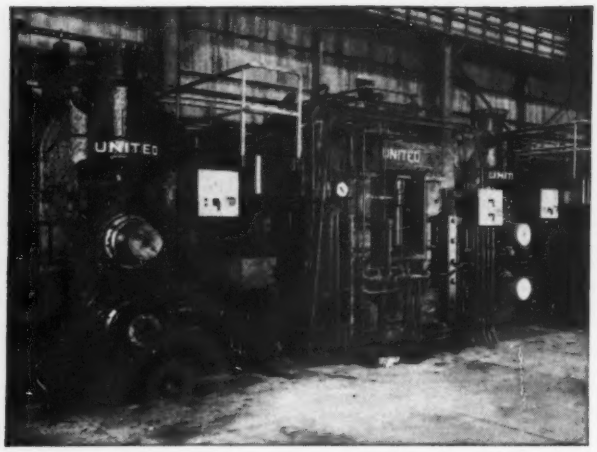

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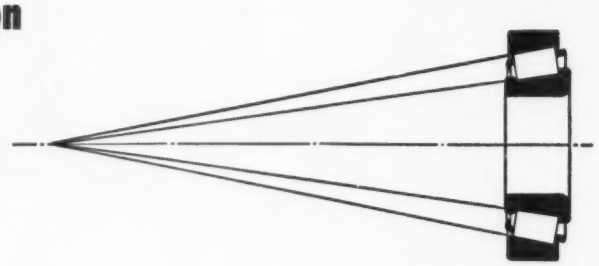

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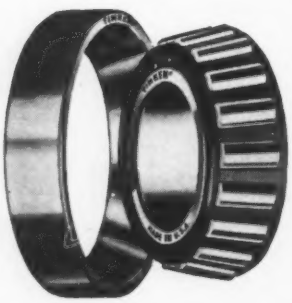

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time traveling

by Jerome P. Levine, '58

As a rule, any mention of time travel or the fourth dimension usually conjures up images of strangely-clad people stepping into a futuristic machine and being whisked off to some remote spot in the future or past. In abstract scientific thinking, though, it is a field of contemplation and speculation. Although having no practical significance at the present time, time travel is a most fascinating subject, giving rise to much theorizing. This article deals with an original hypothesis in this field, which, despite its complete and utter uselessness, I hope will prove interesting.

My main aim is to prove that the popular conception of time—i.e., that a jump into the remote future or past could be accomplished almost instantaneously—is false. Thus I believe that there is no shortcut into the far reaches of time. A time traveler going into the future or past would experience an amount of time equal to that over which he has passed. In all this I assume, conveniently, that time travel will be entirely possible, at least mechanically. Another assumption I make is that time is a fourth dimension. These assumptions are naturally very hypothetical, but for the sake of presenting this theory, they have been made.

Let us picture our three dimensional world moving through the fourth dimension at a constant velocity. The fact that we are moving through the fourth dimension can be explained as the cause of the passage of time in our world. Therefore, for each unit of fourth dimension over which we pass we experience a certain amount of time. This can be compared to a two dimensional world moving through the third dimension at a constant velocity. Picture this as a plane moving steadily in a direction perpendicular to it. This is shown in diagram (1).

This planar, two dimensional world is moving at a definite number of three dimensional units per second or minute. Since seconds or minutes are units of the fourth dimension we can say that the velocity of a two dimensional world moving through the third dimension is measured as a number of three dimensional units per fourth dimensional unit. By similar reasoning it is evident that the velocity of a three dimensional world moving at a direction perpendicular to it into the fourth dimension would be measured as a number of four dimensional units per unit of the fifth dimension. Thus we can express the velocity of this three dimensional world moving through the fourth dimension as seconds-per-f.d.u. (fifth-dimensional unit).

Now let us get back to our two dimensional world moving through the third dimension at a constant velocity. We will give this velocity a value of 2 feet/second. If a two dimensional being develops a way of traveling, independent of his world, through the third dimension, he will be able to travel at a rate different from that of his world. Let us allot to him a velocity of 20 feet/second. He would now be able to travel through the third dimension at a speed ten times that of his world. Thus he could travel over some distance in the third dimension in one-tenth the number of seconds as his world could. In other words to travel over any specified three dimensional distance, the two dimensional world would take some number of four dimensional units (seconds) while our independent person would take one-tenth as many. It is evident, though, that he

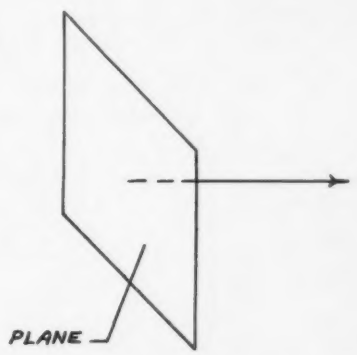


DIAGRAM 1

has still passed over the same number of three dimensional units as his world. He has still experienced that same number of units. Since the third dimension to him is as the fourth dimension to us, the third dimension would be his time. So, despite his power to decrease the number of four dimensional units used up during his travel, he will still experience the same amount of time, as time is to him. He will have merely gained with respect to four dimensional units.

Using the same reasoning, let us picture a three dimensional world traveling through the fourth dimension at 2 seconds/f.d.u. If a three dimensional person now develops a way of traveling independently in the fourth dimension at a speed of 20 seconds/f.d.u., he would be able to travel ten times as fast as his world with respect to f.d.u.'s. Since time to a three dimensional world is in four dimensional units, time to a

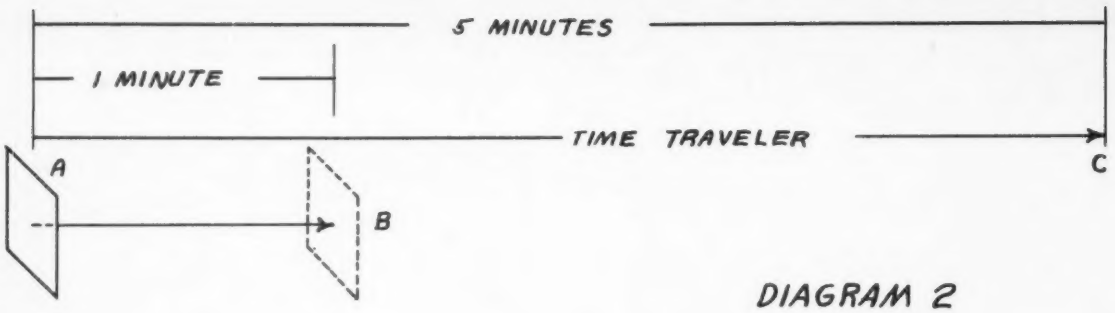


DIAGRAM 2

fourth dimensional world must be in f.d.u.'s. Thus, to a four dimensional being the person would seem to be going ten times as fast as his world. Yet, he would still be covering a certain number of four dimensional units, no matter how many f.d.u.'s he did it in. His power consists in being able to reduce the number of f.d.u.'s he uses up and not in reducting the number of four dimensional units he must pass over to get to a certain position in the fourth dimension. So, despite the decrease in the number of f.d.u.'s the number of four dimensional units experienced is unchanged. In other words, time does not seem to zoom past him. No matter what his velocity in the fourth dimension is, if he passes over two seconds in that dimension, he will still experience and live through two seconds. Therefore, if he was planning to travel to a position in the fourth dimension which would seem to us as sixty years into the future, he would have to be prepared to spend sixty years on the trip. Sixty years of time is sixty years of time no matter how many f.d.u.'s it takes to travel over it just as sixty miles is sixty miles no matter how fast we travel over it. If a three dimensional person had an awareness of f.d.u.'s perhaps it would mean something that we could vary the speed in the fourth dimension, but since we can only feel or measure four dimensions—i. e., length, width, height, and time—this difference of speed only serves to separate the person from his world and not to shorten time experienced.

Actually we cannot call these dimensions the first, second, third, and fourth. They are just four of the dimensions that exist. Since they are the four we know and are aware of we call them the first four. This label is quite arbitrary and has no real significance.

We have determined that independent travel in the fourth dimension involves only the number of f.d.u.'s which are involved. Therefore the traveler, although not seeming to pass time any quicker does leave our world by virtue of the accelerated fourth dimensional velocity. Let us picture in a diagram a course of travel of a three dimensional world and a three dimensional traveler into the fourth dimension. Since we cannot draw four dimensions, we shall reduce everything by one dimension and picture a two dimensional world and traveler moving through a third dimension. We shall still refer to them, though as three and four dimensional.

Letting both the traveler and the world start at A, if we give the world a velocity of 1 minute/f.d.u. and the traveler a velocity of 5 minutes/f.d.u. If diagram (2) represents the happenings during a passage of 1 f.d.u., then the world will have traveled one minute to B, and the traveler will have traveled five minutes to C. At this particular f.d.u. the traveler will have experienced five minutes of time and his world will have experienced only one minute of time. Now if the traveler turned around and headed back the direction he had come from, while the world kept traveling, we find, by the use of simple algebra,

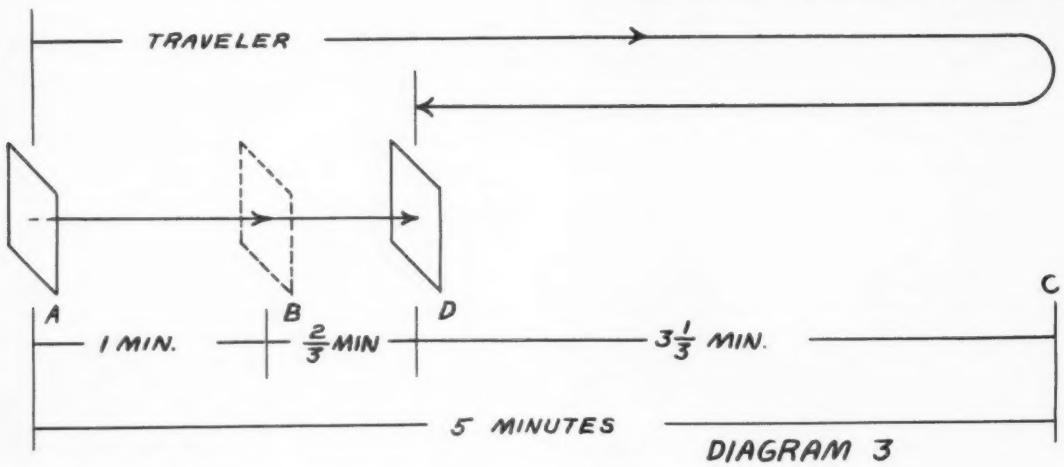


DIAGRAM 3

that he would arrive back at his world when the world is 1 2/3 minutes from A. This is shown in diagram (3).

Now in the same number of f.d.u.'s that his world has traveled 1 2/3 minutes, the traveler has traveled 5 minutes forward and 3 1/3 minutes back. Because of his greater velocity in the fourth dimension, our traveler has been able to travel into the future and return to his world before it could reach the spot to which the traveler had gone. The difficult thing to comprehend is that although it seems to the world that the traveler has been gone only 1 2/3 minutes, he has actually experienced 8 1/3 minutes of time. Thus to travel into the future or past, in addition to enduring the time through which he will have passed, the time traveler will also have to live through another period of time almost as great as the first in order to return to his time. On his return he might find that the world had only passed through a few days of time while he might have passed through many years. Mathematically, the amount of time he would have experienced would compare with the amount of time the world has experienced exactly as his four dimensional velocity compared with his world's four dimensional velocity. Expressed as an equation, this is:

$$\frac{\text{amt. of time experienced by traveler}}{\text{amt. of time experienced by world}} = \frac{\text{4-dimensional velocity of traveler}}{\text{4-dimensional velocity of world}}$$

As an example of how this works, let us go back to our example of above. When the time traveler has returned to his world he had experienced 8 1/3 minutes. Meanwhile the world had experienced 1 2/3 minutes. The traveler's velocity through the fourth dimension was five minutes per f.d.u. while that of his world was one minute per f.d.u. Substituting in the equation:

$$\frac{8\frac{1}{3}\text{ min.}}{1\frac{2}{3}\text{ min.}} = \frac{5\text{ min. / F.d.v.}}{1\text{ min. / F.d.v.}}$$

All this material can be summed up in these statements:

1) Travel in time does not affect the traveler's perspective of time.
2) Time experienced is directly proportional to the four dimensional velocity when traveling in the fourth dimension.

In all of the reasoning in this article I have assumed that a two dimensional world is moving in a straight line at a constant velocity through the third dimension, and that a three dimension world would be moving through the fourth dimension in a straight path at a constant velocity. (Here we define a straight line as the shortest distance between two points independent of the path of light.) The constant velocity was assumed in order to facilitate the work, but it is apparent that even if the velocity was variable, these theories would hold. The only effect of variable velocity would be in the number of f.d.u.'s involved. This would not affect the validity of the theory, though.

If the worlds were not traveling in a straight path, though, there is another factor to be taken into consideration. Picture a two dimensional world traveling in the third dimension on a curved path as shown in Diagram (4).

Thus to get to some point on the path, the world might have to pass over say, ten feet. If

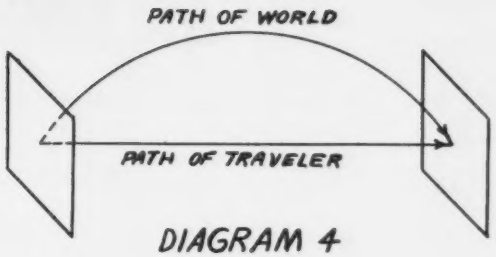
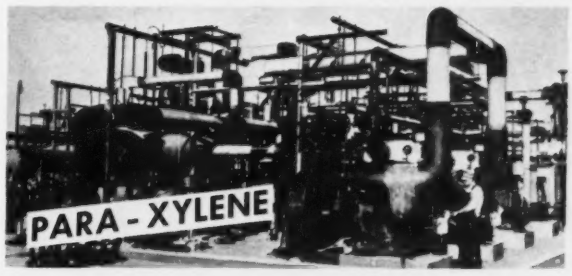


DIAGRAM 4

a person from that world could travel to that point in a straight line instead of along the curved path of his world, he might have only to pass over, say, four feet. Similarly, if a three dimensional world was traveling in the fourth dimension, it might have to pass over, say, ten years to reach some point on its path. If a time traveler could travel in a straight line in the fourth dimension to that point, it might take him, say, only four years to reach that point. Thus he would take less time than his world to reach that point, and he actually would gain in time.

This article has dealt with only one small facet of a most fascinating field. It is not inconceivable that this field will develop into a practical division of physics in much the same way as nuclear physics has. If time travel ever becomes an actual accomplishment, the vague and abstract ponderings of the science fictioneers will undoubtedly have played a dominant part.

Below Right: Three of the six Frick refrigerating machines in service at Big Spring, Texas.



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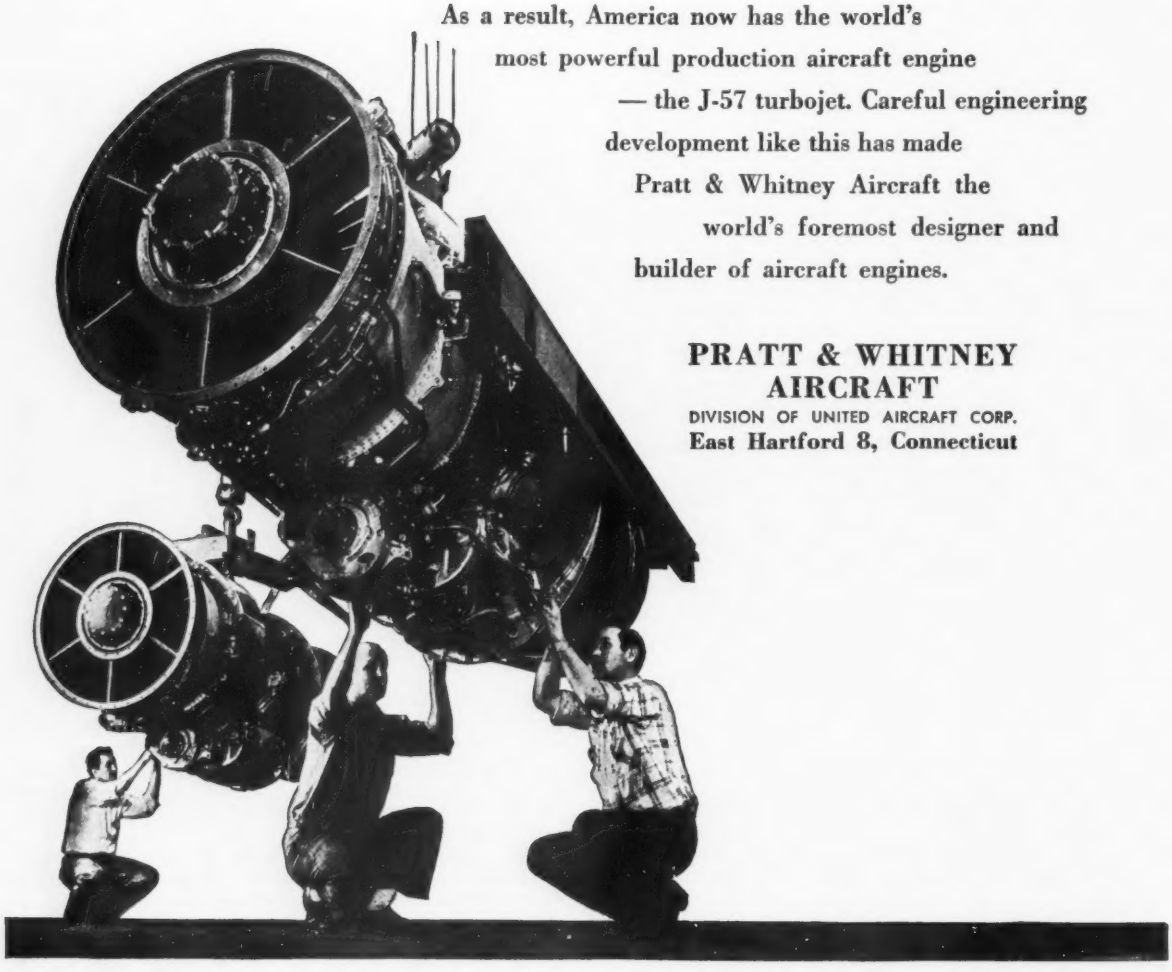

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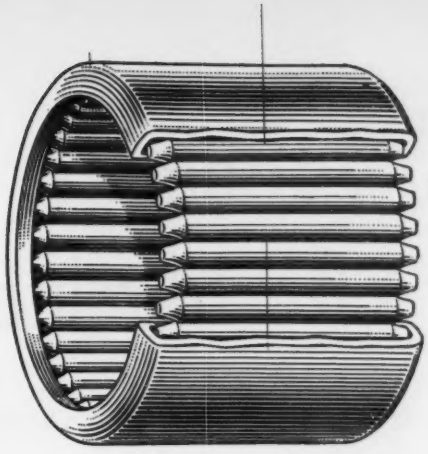

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the magmatic origin of mineral deposits

by D. F. Schraeder and George Logy

An economic mineral deposit consists of a fantastic concentration of the desired mineral with relation to the normal distribution of minerals in the Earth's crust. Oxygen and silicon alone make up more than 74% of the Earth's crust; Aluminum, iron, calcium, sodium, potassium, and magnesium make up another 25%. This leaves approximately 1% of the crust to all other elements. The percentage by weight of a few of the more commonly sought elements, in an average ten miles depth of the Earth's crust, is given below.

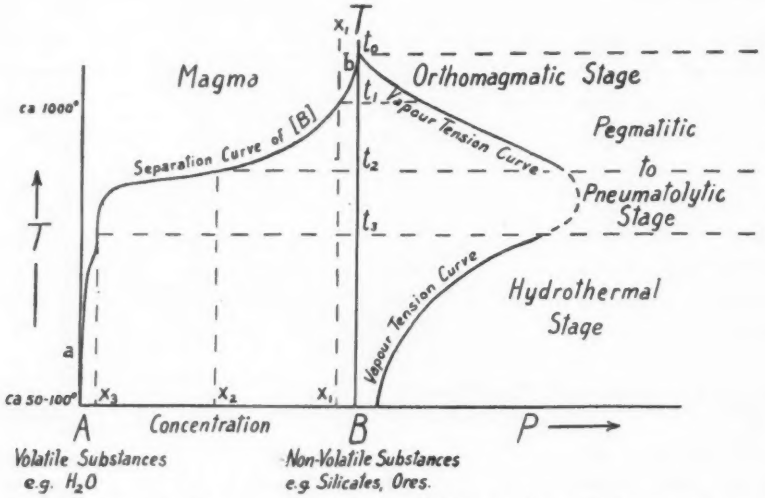
Iron	5.01%
Nickel	0.20%
Copper	0.01%
Uranium	0.008%
Zinc	0.004%
Lead	0.002%
Tin	0.000,n%
Silver	0.000,00n%
Gold	0.000,000,n%
Germanium	0.000,000,00n%

As small as the concentrations are, an even smaller amount is available in mineral forms which are economically worth mining. The minerals sought are found in both hypogene and supergene deposits; therefore, to find economic deposits a knowledge must be had of their genesis.

It is assumed that all minerals were originated from a magmatic source, and that some minerals remained with the solidified magma while others were separated, by physical and chemical means, from this source. In order to follow a logical sequence in the study of mineral deposits a study of the magmatic genesis should be undertaken.

Due to the scattering of radioactive materials throughout the Earth an average of one microcalorie per square-centimeter per second reaches the surface. In some places it is determined that the radiogenic heat produced, from a nonlinear distribution of radioactive substances, is sufficient to cause the surrounding rocks to melt and form a magma. If any structural weaknesses exist about a magmatic volume, the melt would migrate in order to maintain a pressure equilibrium. In some cases the magma is intruded into the surrounding country rock and in others it is extruded to the surface. A plot of the active volcanic activity on the Earth indicates that the activity lies predominately in belts which lie adjacent to geosynclinical areas. An example is the Japanese island arc system. Another example indicating this phenomenon was illustrated in 1947 by Eardley when he postulated a volcanic island arc system, off the west coast of the United States, in order to explain the extrusives in the sediments of the Cordilleran Geosyncline.

Since recent evidence and calculations show that the outer portion of the Earth's mantle is probably solid, the simple postulation that the bottom of a geosyncline breaks into the molten por-



T-X and P-T Diagram of a System containing One Volatile and One Refractive Component.

Saturation-curve of B under its own vapour tension.

tion of the Earth releasing magma for an upward journey can be, at present, disregarded. However, due to the "blanketing" effect of the geosynclinal sediments, plus their own radioactivity, "hot spots" may be more readily initiated where the surrounding rock can be transformed to a magma. This hypothesis fits the evidence, and radiogenic heat will be considered the prime cause of magmatic genesis. Other, probably minor, causes contributing heat are the latent heat of the Earth, and the heat caused by orogenic movement.

Once the magma is formed forces begin to act to differentiate its constituents into separate parts. If it were not for this action, the magma upon cooling would leave no economic enrichment of syngenetic minerals sought. Several theories have been propounded to explain the differentiation of a magma. In particular magmatic environments each of the theories probably exerts a strong influence.

In a magma, containing a solution of numerous minerals, some differentiation will occur due to the gravitational settling of separate parts. Although, as N. L. Bowen states, this effect may be negligible in a viscous magma, it will probably have an appreciable effect when the magma has a low viscosity and there is sufficient time for this differentiation to take place.

If two portions of the magma are immiscible, analogous to oil and water, the separate solutions will separate, in time, due to gravity; the denser liquid will move to the bottom of the magmatic reservoir. Generally, magmas will contain substances which will be miscible in all proportions, but in the case of a basic magma rich in iron and silica, liquid immiscibility may be important in its differentiation.

Gas transfer is another factor which influences magmatic differentiation. When the pressure on the magma reservoir decreases the volatile components will bubble to the top of the reservoir. These gas components will flotate other constituents, as in ore dressing. Since this stage, low pressure, usually occurs after crystallization has commenced, it could be called one of the effects of fractional crystallization. Turner and Verhoogen also mention an effect called "gas streaming", where the residual fluids of the magma are forced by the volatiles through the crystal mesh to the top of the magma volume. This effect necessarily takes place late in the crystallization program and probably makes itself felt in pegmatitic deposits. (In order to have a gas phase, however, the partial pressure of the volatiles must exceed the pressure exerted on the magmatic volume. In many cases, then, there will never be a gas phase until after the pegmatitic stage of the Niggli T-X and P-T diagram.)

Contemporary petrographers consider fractional crystallization the fundamental means of magmatic differentiation. As the temperature of the melt decreases various minerals precipitate out of solution in crystal form. The heavier minerals drop to the bottom of the reservoir thereby forming, in the magmatic volume, a layered series of minerals. Convection currents and thermal diffusion in the magma aid in the distribution of the minerals. Excellent examples of differentiation due to fractional crystallization are illustrated by: the Skaergaard instrusion of Greenland, The Bushveld Complex of South Africa, the Stillwater Complex of Montana, and locally the Hudson Pallisade Sill in New Jersey. These intrusions clearly show the mineral banding due to fractional crystallization. A dynamic effect of fractional crystallization is called "filter pressing." If a tectonic movement occurs while the magma is partially crystalized the remaining fluid, placed under the attendant pressure, will be forced to move to a new position in order to relieve the pressure; thus the later portion of the melt will be concentrated.

The pressure exerted by the magmatic material increases as the magma cools (as seen in the Nigsli Diagram); so that any weaknesses in the structure next to the melt will permit passage of the magmatic material, if the pressure is high enough. Porous rock, sandstone, will allow greater passage than non-porous rocks such as slates. Chemical properties also affect the migration of a magma, allowing the magmatic fluids to permeate through them, and alter them. But, the greater portion of the magma probably remains in place; and if any mineral deposits are to be directly associated with the bulk, then they must have been formed by magmatic differentiation.

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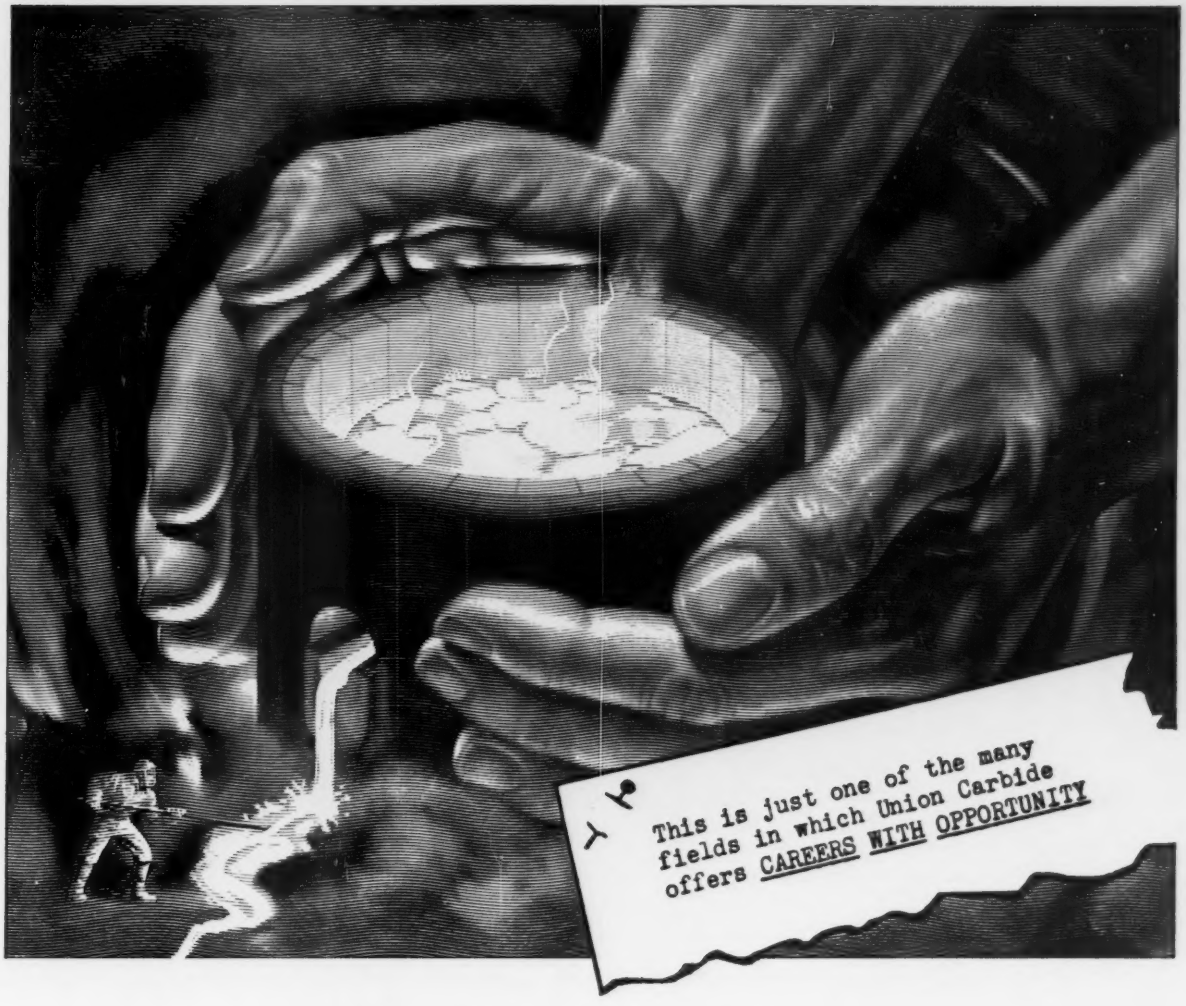

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record review

by Klaus Kubierschky

Geminiani:

Six Concerti Grossi, op. 3
Barchet String Quartet, Pro Musica String Orchestra, Rolph Reinhardt, conductor
VOX

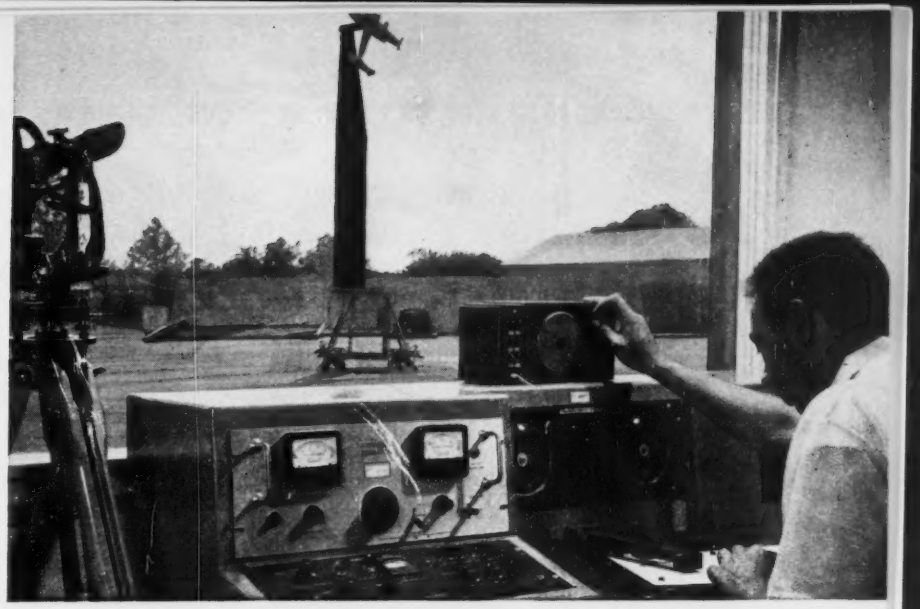
The extent to which a good performance can affect the significance of a piece of music is clearly seen in this recording. Abandoned in the midst of a crowd of more important compositions, Geminiani's Concert Grossi were left to lesser orchestral groups. The by now famous Pro Musica Orchestra of Stuttgart, Germany, has the credit of recalling to our attention many a half forgotten work, and in this case they really make our listening worthwhile.

Mozart:

Symphony no. 41 (Jupiter)
Sir Thomas Beecham, Royal Symphony Orchestra
Columbia

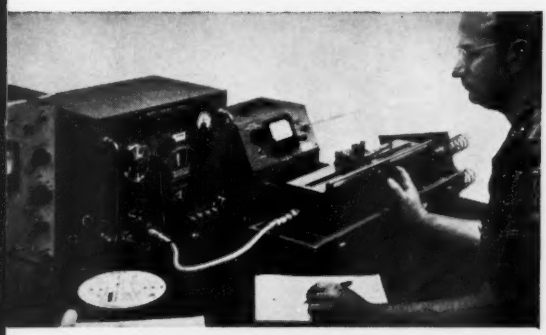
Many a conductor seems to think that Mozart's "Jupiter" is merely a piece of music for its imposing effect on the listener. Very few have come to realize, as Beecham has, that Mozart was almost constantly in agony, that his emotions were by no means trivial, and that the beauty transpiring from his works was by no means a mere fiddling around with notes.

Thus the Beecham recording is very difficult and not satisfying in the usual sense. Those who are interested purely in the sound of the music will welcome this recording enthusiastically. However, the listener for whom a symphony is an emotional experience, will welcome this recording and place it on the top of his preference list.



Electronics Research Engineer Irving Aine records radiation antenna patterns. Twenty-two foot plastic tower in background eliminates ground reflections, approximates free space. Tower is of Lockheed design, as are pattern integrator, high gain amplifier, square root amplifier, logarithmic amplifier.

Antenna development program at Lockheed expands



Electronics Research Engineer F. R. Zboril measures input impedance of a scale model helical antenna array used for ground tracking of missiles. Most of Lockheed's other antenna work involves advanced research studies on flush mounted antennas.

Lockheed's diversified development program presents Electronics Engineers qualified for airborne antenna design with a wide range of assignments in communication, navigation and microwaves. Antenna design is one of the fastest growing research and development areas at Lockheed.

Studies embrace virtually all types of aircraft, including the Super Constellation radar search plane—a type of aircraft developed and produced exclusively by Lockheed.

Career Positions at Lockheed

Lockheed's expanding development program has created a number of positions for Electronics Engineers and Physicists to perform advanced work in antenna design.

In addition Lockheed has a number of positions open for engineers in aerodynamics, thermodynamics, flight test analysis, structures and design to perform advanced studies on such diverse projects as: Applications of nuclear energy to aircraft, turbo-prop and jet transports, bombers, trainers, supersonic aircraft with speeds surpassing Mach 2, and a wide range of classified activities.

Program for Advanced Study—To encourage members of its engineering staff in study leading to advanced degrees, Lockheed reimburses 50% of the tuition fee upon successful completion of each course relating to the engineer's field at the University of Southern California and University of California at Los Angeles. Both universities offer a wide night school curriculum in science and engineering.

E. O. Richter, Electronics Research department manager (seated), W. R. Martin, antenna laboratory group engineer (standing), and J. L. Rodgers, electronics research engineer, discuss design of corrugated surface antenna.

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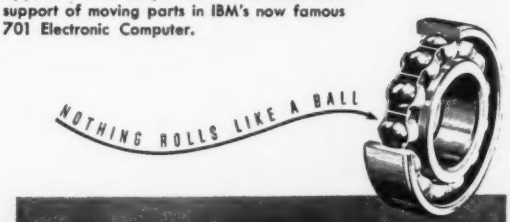

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eulogy on the differential analyzer

by Roger D. Wollstadt

For the last seventeen years, room 7-303 at M.I.T. has been the home of the original "giant brain," the M.I.T. Electro-mechanical Differential Analyzer. Since 1942, the differential analyzer has served as a high-speed analog computer, a training ground for computation personnel, and a proving ground for new ideas in automatic computation. Now, the differential analyzer is being dismantled; its parts are being scattered to the four winds. Just why would a giant computer be scrapped? Why should a machine which is still capable of doing all the tremendous operations for which it was designed be set aside? And what is the history of the differential analyzer? These are the questions to which TEN have sought the answers.

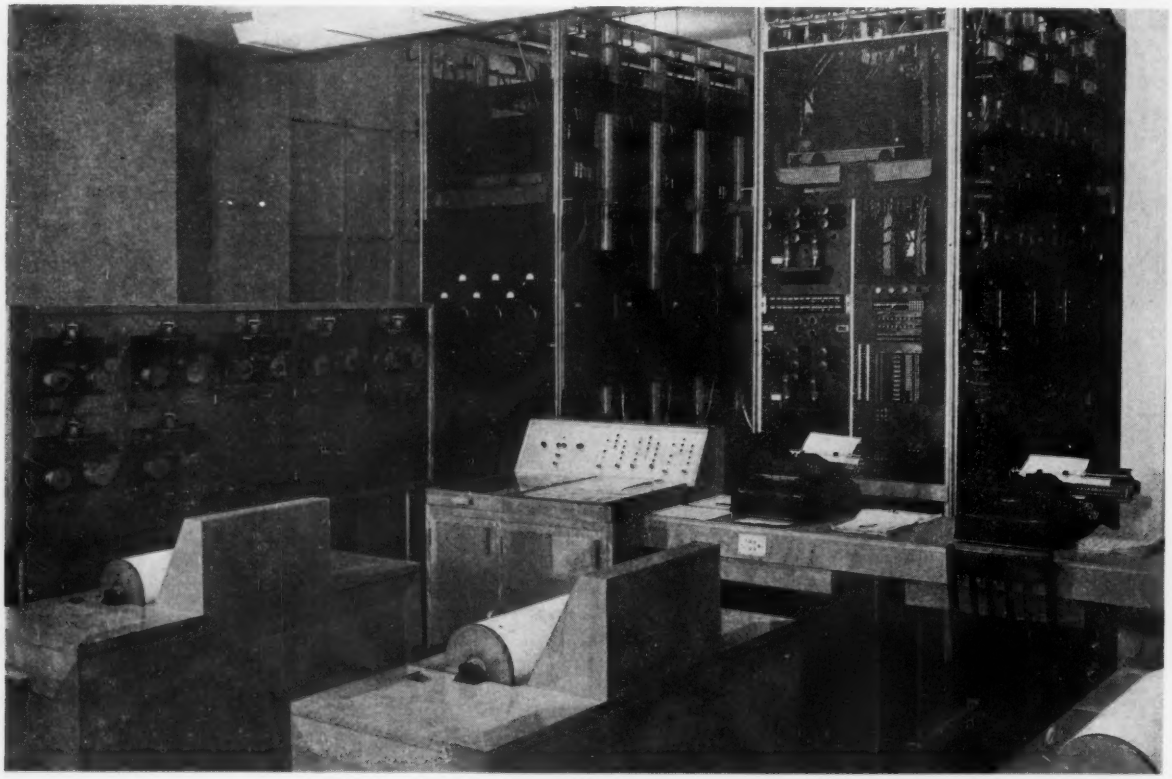
The electromechanical differential analyzer was in full operation from February, 1942 to July, 1954. It was preceded by a mechanical differential analyzer. This machine had been preceded by a still earlier machine, the product integraph.

The product integraph was the first computer which was able to handle integration. It was built at the Institute in the early 1920's by Vannevar Bush, F. D. Gage, and H. R. Stewart of the Electrical Engineering Department and was placed in service in 1925.

In 1930, the world's first true differential machine was introduced by Dr. Bush and Professor Harold L. Hazen, the present Dean of the M.I.T. Graduate School. This machine was entirely mechanical in proportion and was accurate to approximately three significant figures. It was sent out to Wayne University in Detroit in 1945, and is now operating there.

In 1935, through a grant from the Rockefeller Research Foundation, D. Bush and Dr. Samuel H. Caldwell initiated a study of a complete redesigning of the differential analyzer so as to make it the first true large-scale computing machine.

General View Of Machine.



Actual construction was started in June, 1937, and the machine was put into full service in February, 1942, well ahead of Harvard's Mark I, the first large-scale digital computer.

The electromechanical differential analyzer had a capacity for solving problems unequalled by even most of the computers built today. It contained eighteen integrators, which were the "heart" of the machine. These integrators, unlike the integrators on most analog machines, could integrate anything with respect to any variable. Furthermore, if more than one integrator were used, integration with respect to more than one variable at a time could be done. The eighteen integrators made the machine capable of solving eighteen order differential equations. In practice, however, this computing power was used to solve sets of equations simultaneously or to work up to three separate problems at once. In the field of differential equations, the differential analyzer's only practical limitation was that it could solve only ordinary differential equations, and not partial differential equations.

The differential analyzer also contained differential gear boxes for addition and subtraction, counters, variable units, typewriter output units, graph-drawing units, and a photo-electric curve following device. All of these units could deal with two or more continuous variables and give out continuous results. All of the components were essentially mechanical devices which were electrically connected.

The differential analyzer had several distinct advantages over both digital machines and most other analog computers. Its advantages over digital computers were those inherent in analog devices. One was that it could handle continuous variables and continuous processes as such. Another was that problems could be prepared for solution with a minimum of programming and coding. The differential was superior to most other analog machines inasmuch as the integrators could function with respect to more than one variable at once.

During World War II, the differential analyzer was used by the Ballistics Research Laboratory of the Navy Department and by other defense agencies for the calculation of ballistics tables. Later, at the time of the "Korean conflict," it solved problems concerning jet gunfire. During the last three years of its existence, it was used by the M.I.T. Instrumentation Laboratory in work connected with the design of aircraft armaments and sights for use in air-to-air combat.

During the twelve years of its use, the differential analyzer served at least two purposes apart from its calculation duties. First, it served as a proving ground for the theories connected with large calculators; it was proof that calculators could be built and made practicable even though they contained thousands of relays and vacuum tubes. Second, it was used as a training laboratory for operators and designers of other large-scale computers, both analog and digital.

On June 18, 1954, the order came that the differential analyzer was to be dismantled. Time had caught up with it. To be exact, time, economics, and scientific development had caught up with it.

When it was built, the differential analyzer was the foremost computer in the field. But since then, computers have been developed which give results faster, more accurately, and, most important, more economically for a given speed and accuracy. The differential analyzer finally became obsolete and had to give way to the new computers. As Dr. Caldwell put it, "Things do go obsolete on you—that's one of the chances you take in scientific development."

Practically all of the differential analyzer was at least twelve years old when it was dismantled. The mechanical parts were all seventeen years old. Contrast these ages with the five years that is considered the normal life span for a modern computer. Although the differential analyzer had been years ahead of its time when it was constructed, it had become, for most practical purposes, relatively inefficient. Furthermore, its cost in maintenance and space had become disproportionate to its usefulness.

Much of the differential analyzer's work can be done much more efficiently by digital computers and other analog computers. Most of its work does not require the five-significant-figure accuracy that the differential analyzer gives. This work can be done more efficiently on the less accurate, but faster, Reeves Electronic Analog Computers (REAC's).

The most complex work can be transferred to the M.I.T. Whirlwind, the world's fastest computer. M.I.T. also has several other digital machines which will handle less complex work that requires accuracies up to thirteen significant figures.

Very little of the differential analyzer is being salvaged for actual computation work. Six of the eighteen integrators are being sent to Purdue University, along with a few minor components. Some of the other components have been sent to scientific museums in Boston and Philadelphia. The rest of the components are being distributed among the various laboratories and scientific societies in the Institute.

The differential analyzer can be considered symbolic of present-day scientific progress. It shows the tremendous pace of research and development in the field of electronics. It is also an indication of the great strides being made in other fields of science. It is, in some respects, a heartening thing to see that such a machine as the differential analyzer is being supplanted; a true measure of scientific progress could well be the number of previously considered indispensable quantities which are no longer needed.

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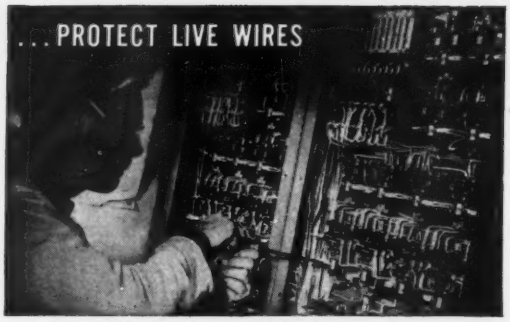

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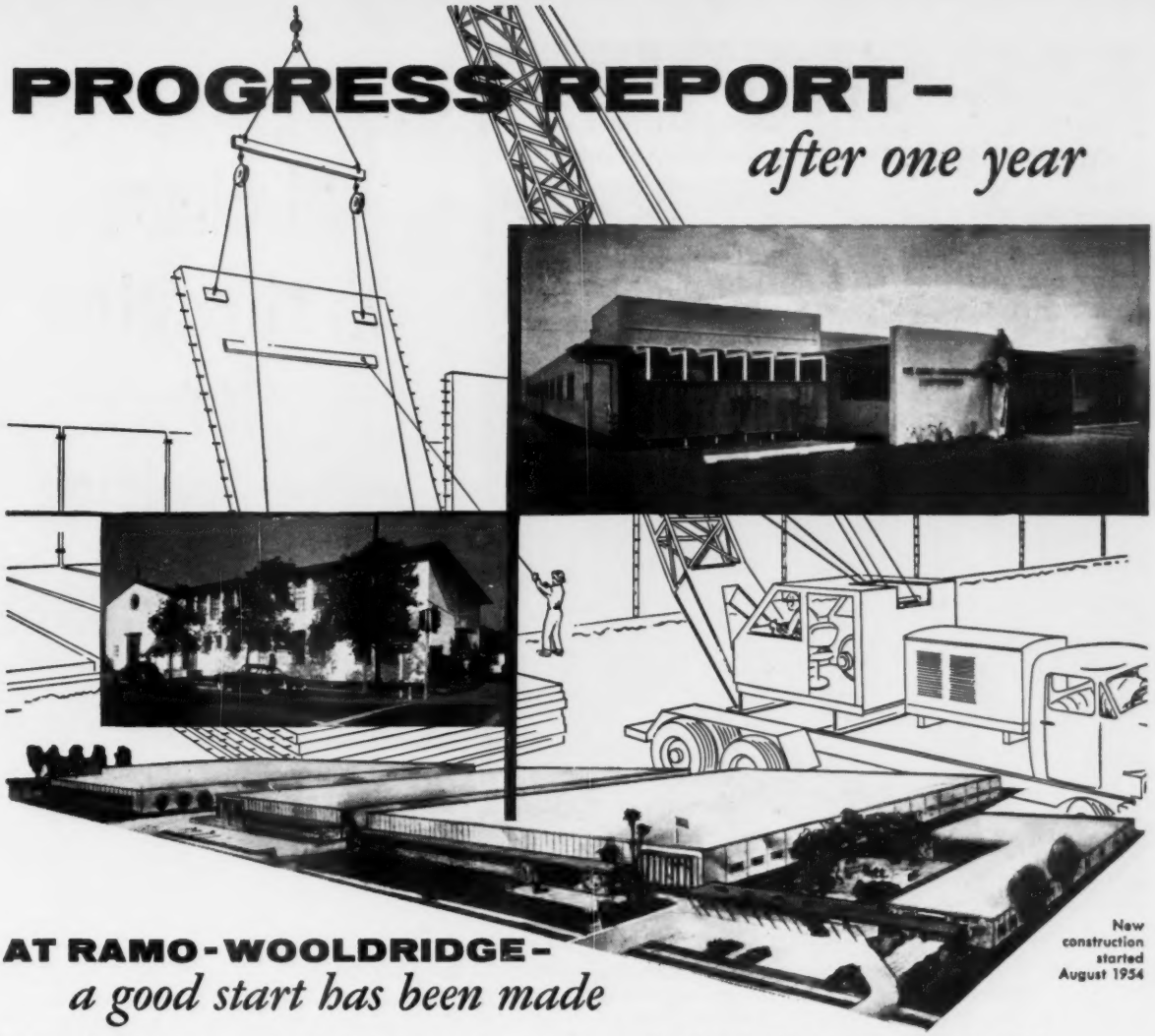

New construction started August 1954

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WHO ARE INDUSTRY'S TOP YOUNG SCIENTISTS ?

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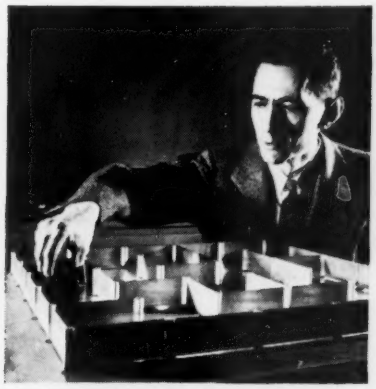
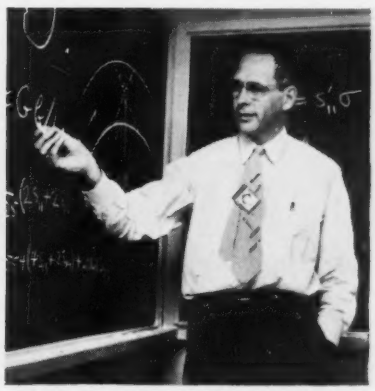


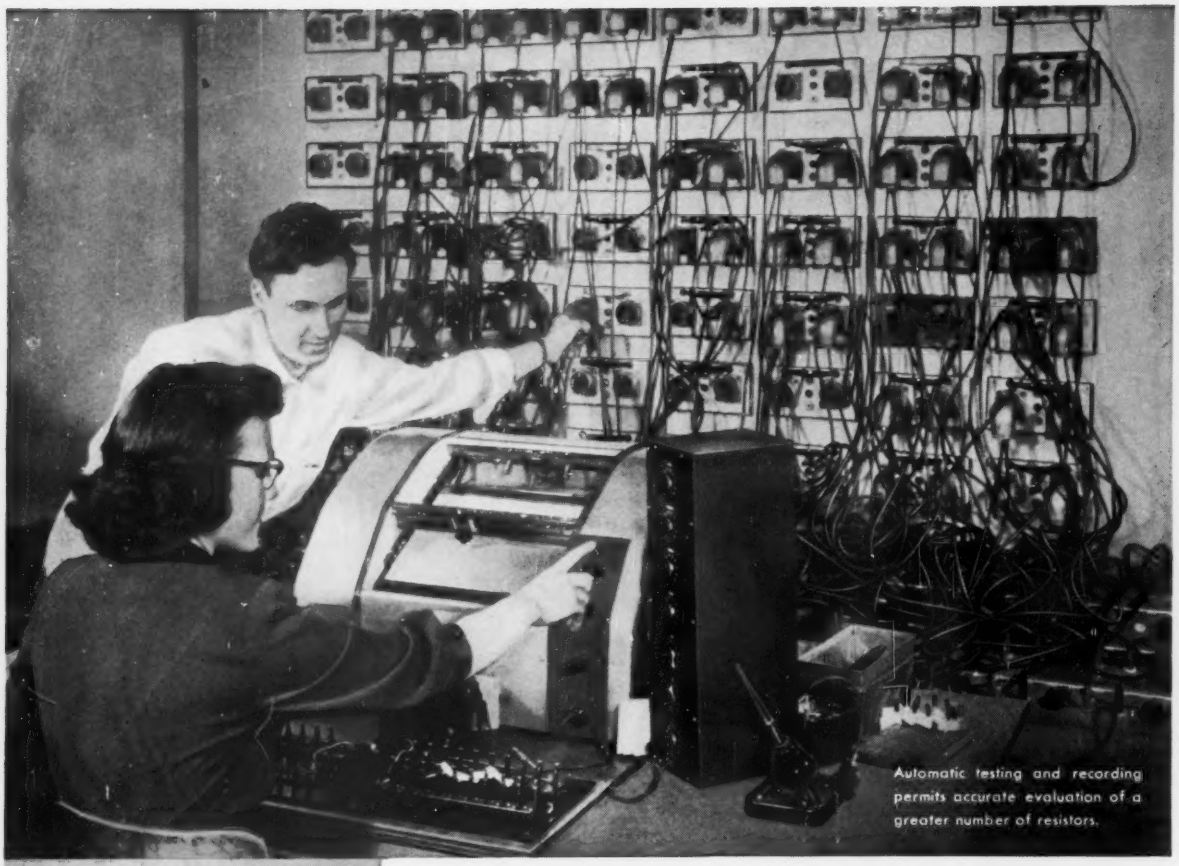
Mathematician Claude Shannon won fame for his Communication Theory

Physical Chemist William Baker introduced new concepts that have improved synthetic rubber and fibers



Physicist Conyers Herring is known for his understanding of the quantum mechanics of the solid state

BELL TELEPHONE SYSTEM

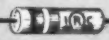


Automatic testing and recording permits accurate evaluation of a greater number of resistors.

BASIC REQUIREMENTS

JAN and MIL Specifications are basic guideposts for electronic advancement, whether used as engineering reference points or as procurement standards. IRC's dual emphasis on mass production and exacting testing assures highest performance standards at lowest possible cost.

SPECIFIC EXAMPLES



Type BT Insulated Composition Resistors
MIL-R-11A Specification

IRC Power Wire Wound Resistors
MIL-R-26B Specification

Type BW Low Wattage Wire Wounds
JAN-R-184 Specification

Sealed Precision Voltmeter Multipliers
JAN-R-29 Specification

ONLY IRC MAKES SO MANY JAN AND MIL TYPE RESISTORS

. . . another reason why engineers prefer IRC Resistors

56 different IRC resistors is today's figure—all equivalent to JAN or MIL specifications. Manufacturers of military equipment who must meet these specifications depend on IRC for all their resistor requirements. Offering the widest line of resistors in the industry—138 different types in all—IRC is the logical source of JAN and MIL type units.

IRC

Wherever the Circuit Says —vvv—

INTERNATIONAL RESISTANCE CO.

401 N. Broad St., Phila. 8, Pa.

In Canada: International Resistance Co., Toronto, Licensee

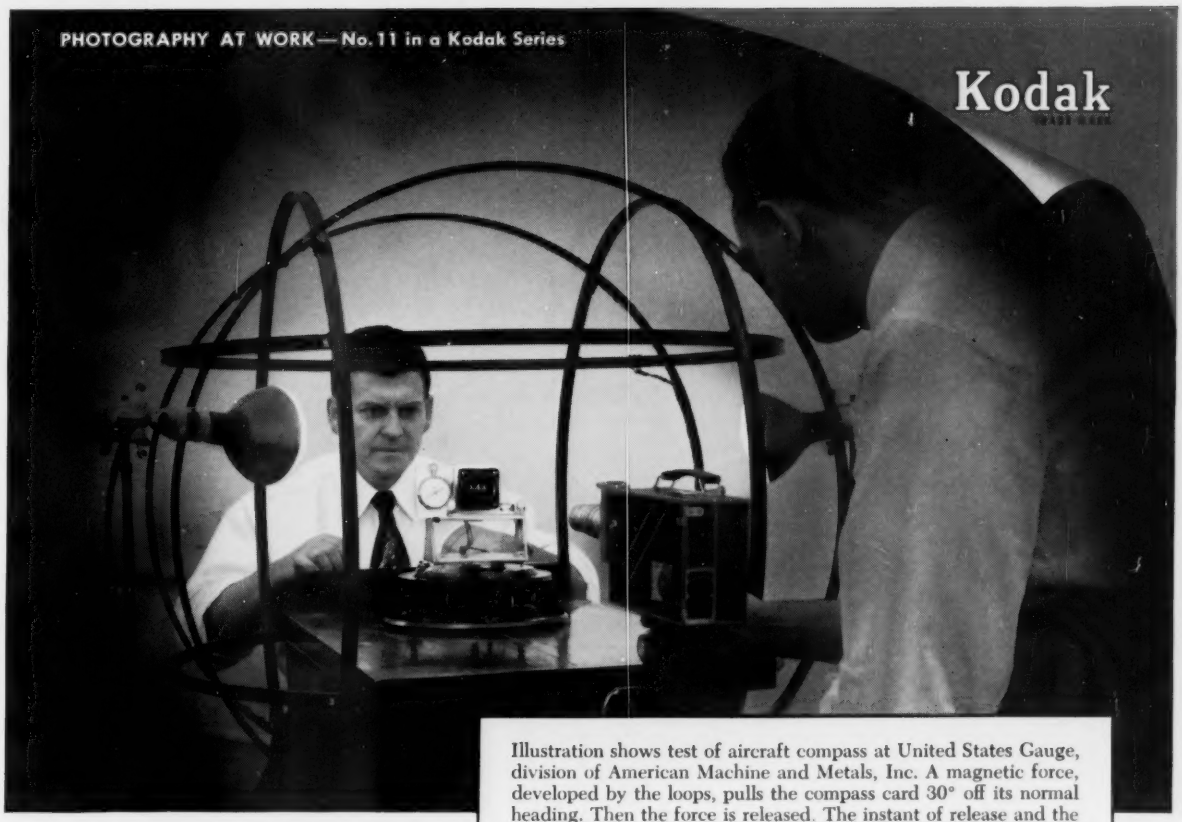


Illustration shows test of aircraft compass at United States Gauge, division of American Machine and Metals, Inc. A magnetic force, developed by the loops, pulls the compass card 30° off its normal heading. Then the force is released. The instant of release and the moment the compass recovers by 5° are both recorded on the film—become positive evidence of proper performance.

Wanted: an inspector with a split-second eye —*photography got the job*

A difference of 2/10ths of a second means the compass passes or fails. So the maker pits it against a stop watch—gets definite proof of performance with movies.

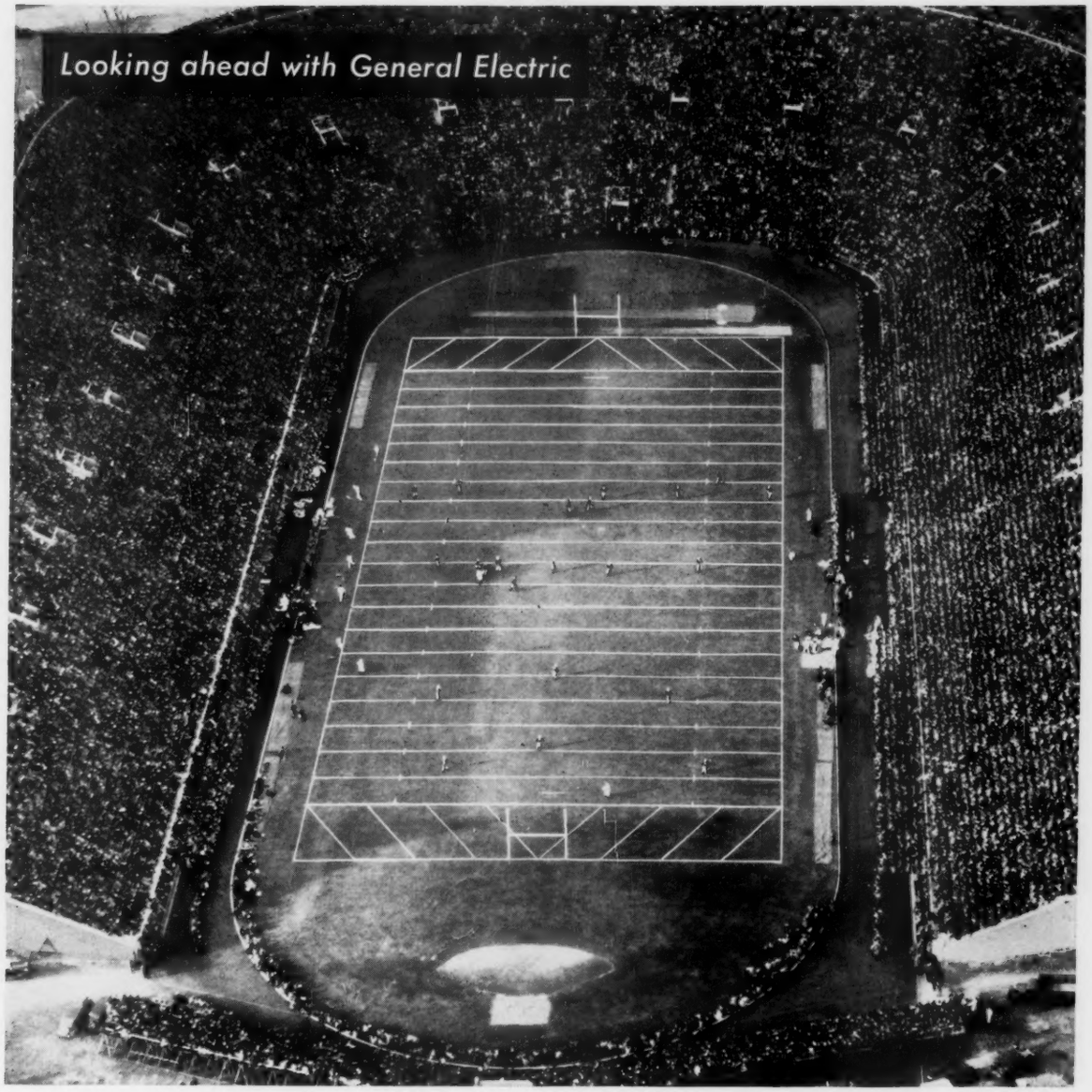
Uncle Sam said this aircraft compass must respond by 5 degrees in not less than 1 second or more than 1.2 seconds. That's only 2/10ths of a second leeway—far too little for human hands and eyes to catch the action accurately.

So, side-by-side, the stop watch and compass act their parts before the movie camera. Then individual frames along the film show the precise instant that the 5-degree mark is reached.

Product testing and quality control are naturals for photography. They are typical examples of the many ways photography works for businesses, large and small. It is improving production, saving time, reducing error, cutting costs.

Graduates in the physical sciences and in engineering find photography an increasingly valuable tool in their new occupations. Its expanding use has also created many challenging opportunities at Kodak, especially in the development of large-scale chemical processes and the design of complex precision mechanical-electronic equipment. Whether you are a recent graduate or a qualified returning service man, if you are interested in these opportunities, write to Business & Technical Personnel Dept., Eastman Kodak Company, Rochester 4, N. Y.

Eastman Kodak Company, Rochester 4, N. Y.



45,000 G-E people working on jobs created by new products since 1945 could almost fill Princeton's Palmer Stadium.

In 9 years, new products created G-E jobs for enough people to fill a football stadium

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